How far is it? Distance measurements and their consequences
Part I

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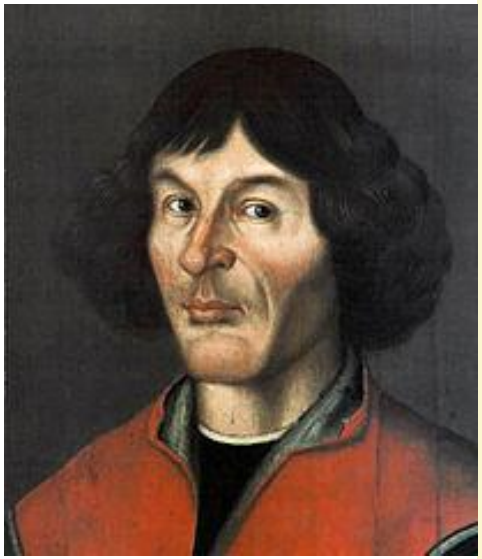
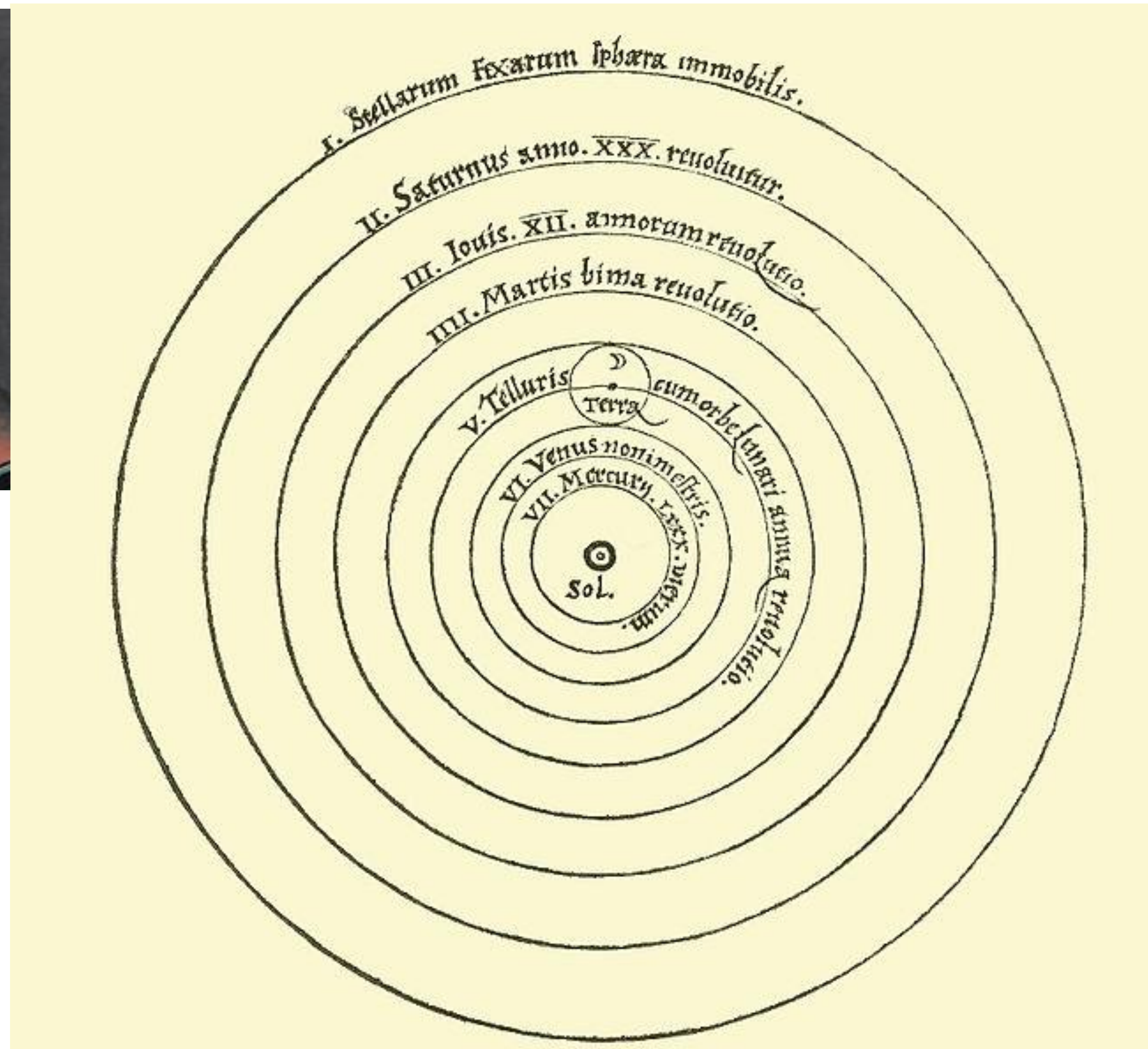
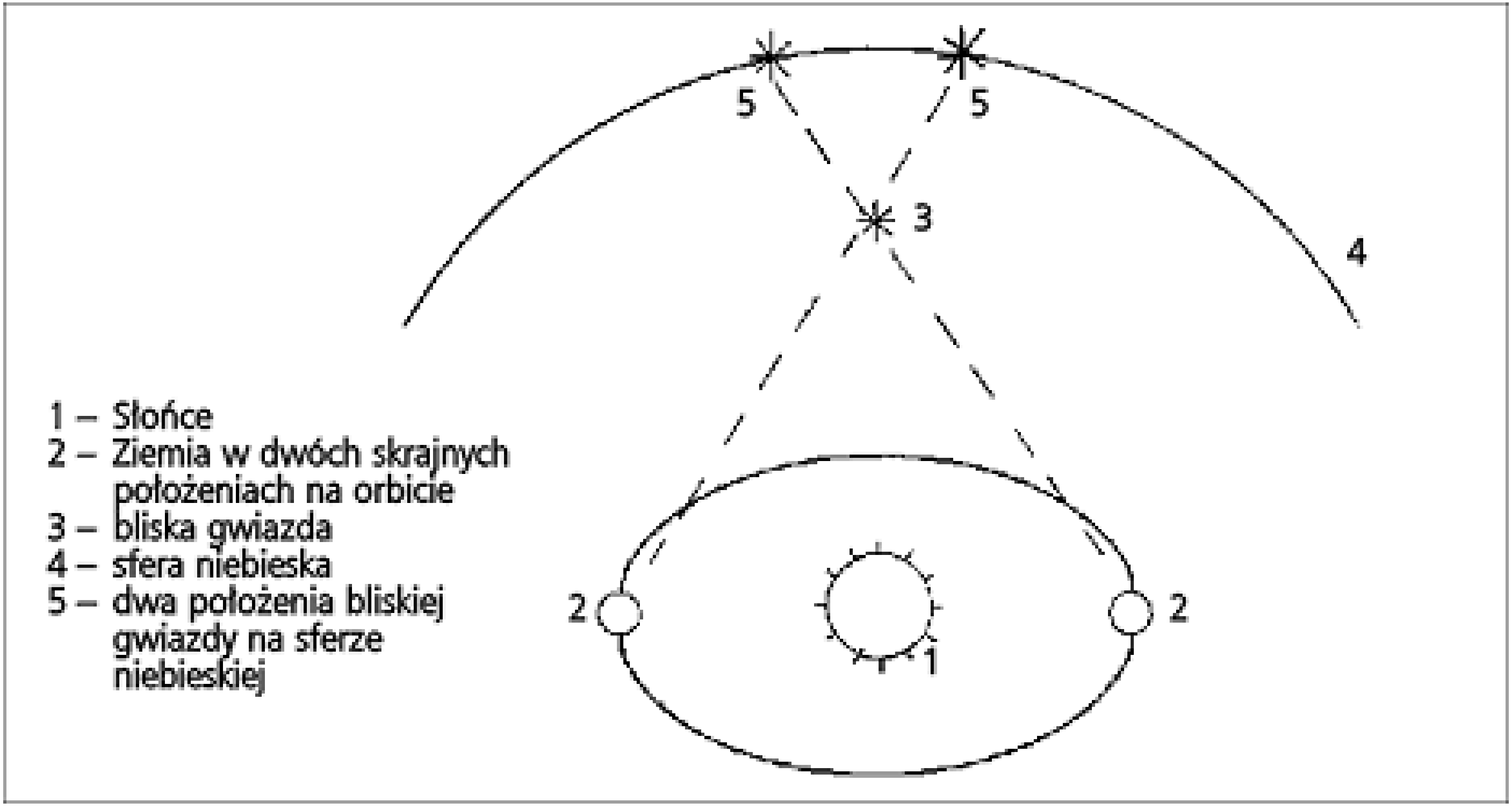
Copernicus model of the Universe

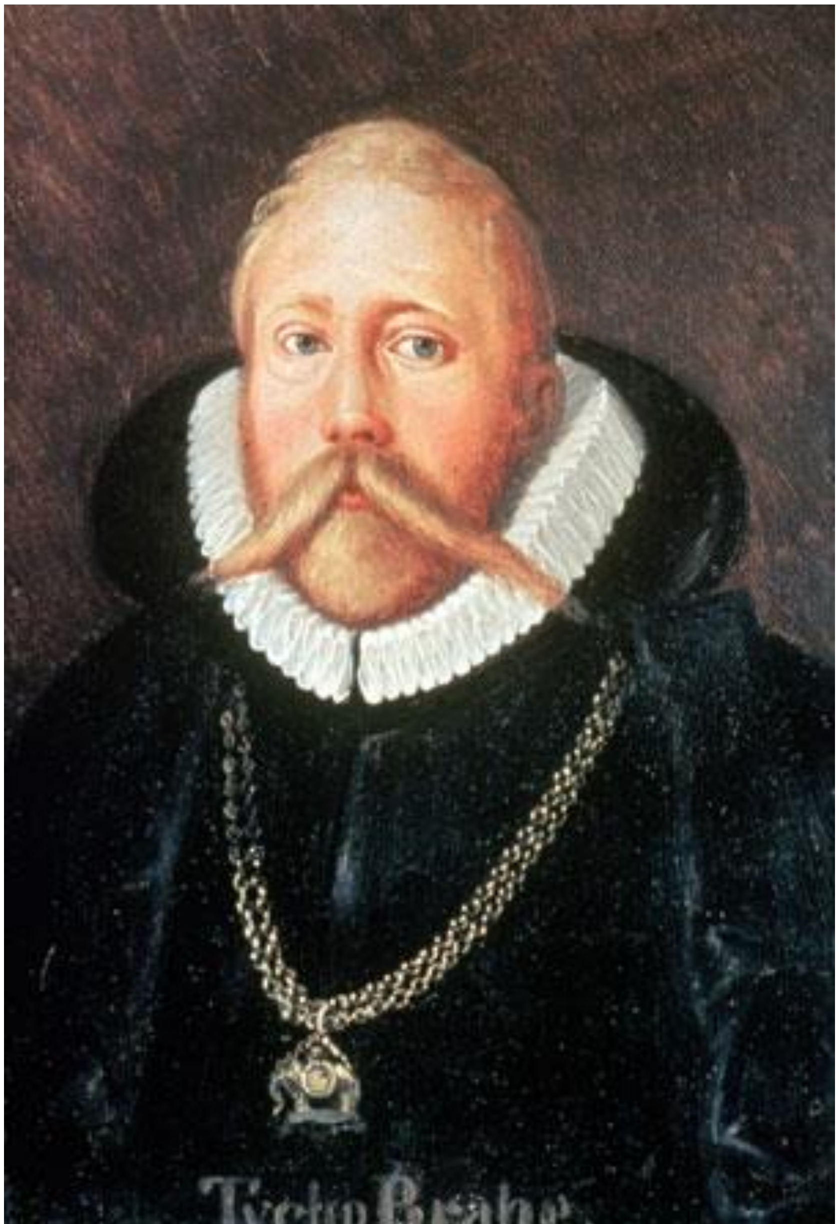


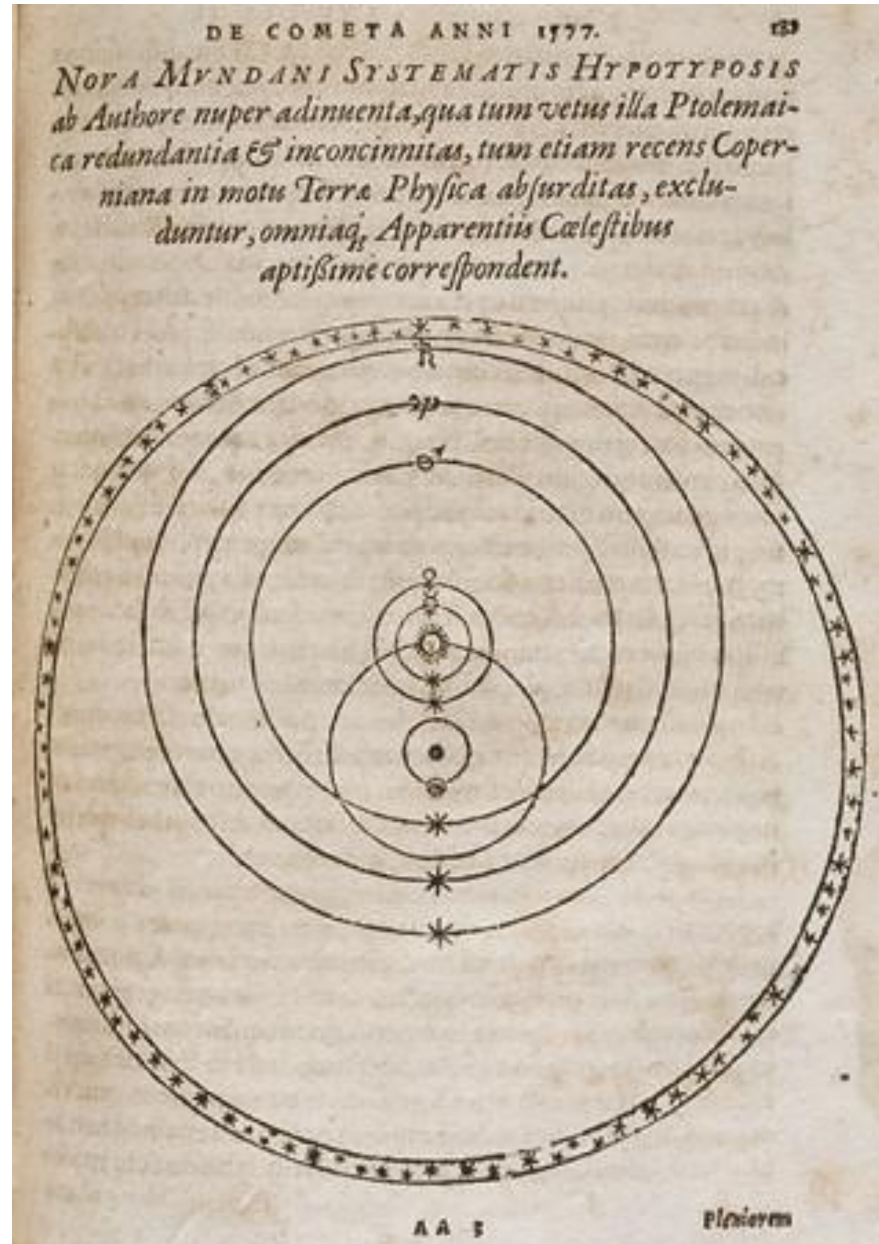


The expected parallax



Tycho de Brahe was afraid of the lack of parallax…



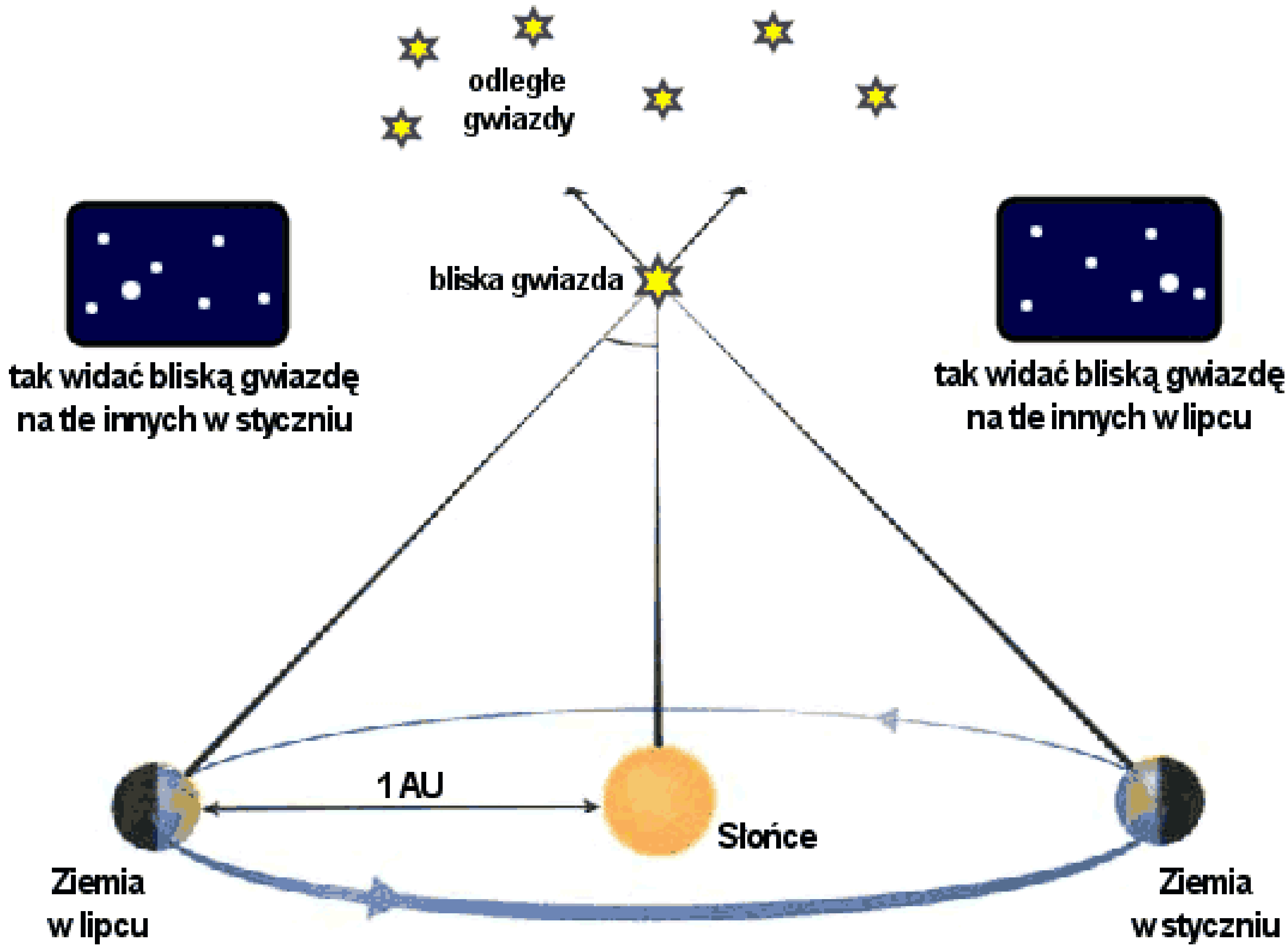


DE COMETA ANNI 1577. 189

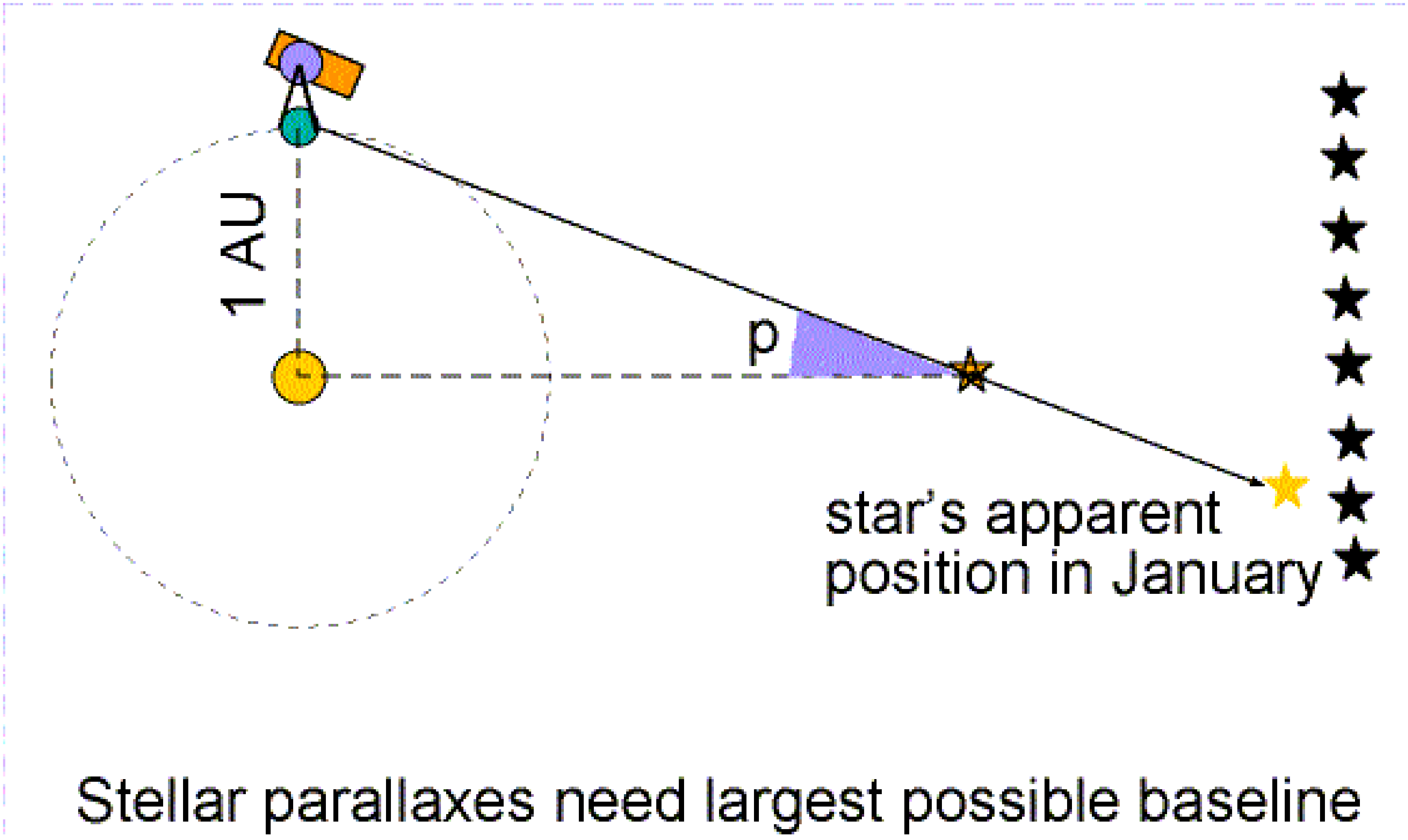
Nova Mundani Systematis Hypotyposis ab Authore nuper adinuenta, qua tum vetus illa Ptolemaica redundantia & inconcinnitas, tum etiam recens Copernicana in motu Terræ Physica absurditas, excluduntur, omniaq; Apparentiis Cœlestibus aptißime correspondent.

AA 3

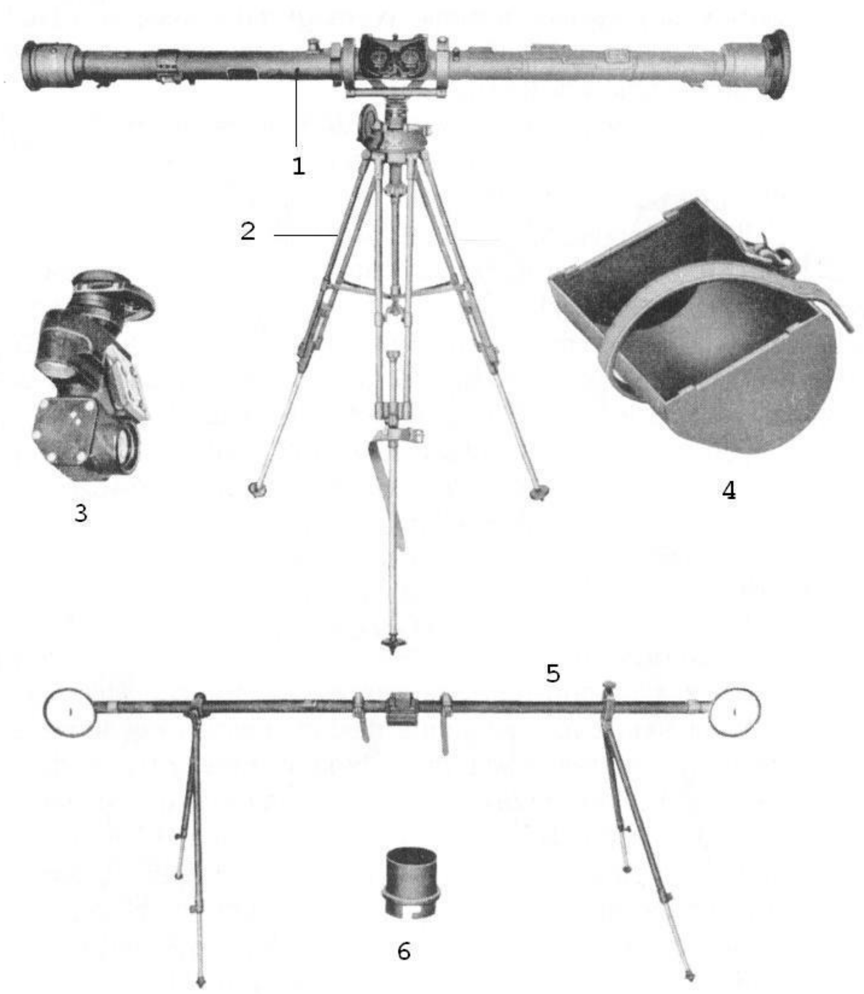
Parallax changes position of a bright star on the background of faint ones



Definition and method of measurement

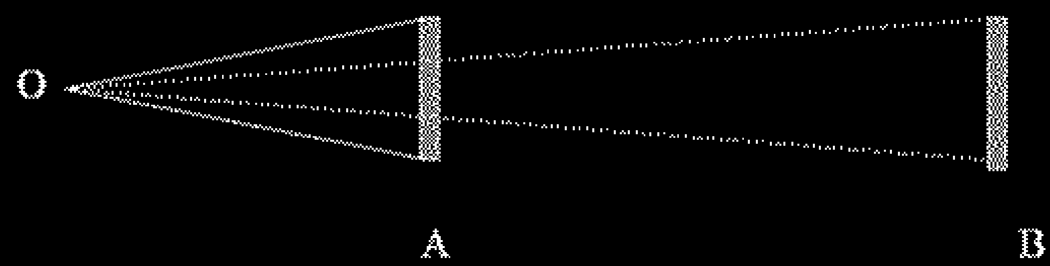


Astronomers apply the same principle as artillerists…



1. dalmierz
2. trójnóg
3. lunetka
4. przykrywka oczników
5. sprawdzacz
6. zaciemniacz

Schematic sketch of the principle



Each rod is the same length. However, it is clear that rod A appears larger to the observer, O. The angular size of each rod is given by

Angle ~ (length of the rod) / (distance to the rod)

F.W. **Bessel**, Monthly Notices of the Royal Astronomical Society, 4, 152 (1838)

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For the Star a.

			Mean Error.
Mean distance for the beginning of 1838	....	461″·6094	
Annual variation $= +4''\cdot3915 - 0''\cdot0543$	....	+4 ·3372	±0″·0398
Difference of annual parallax of 61 and a ...	$\alpha'' =$	+0 ·3690	±0 ·0283

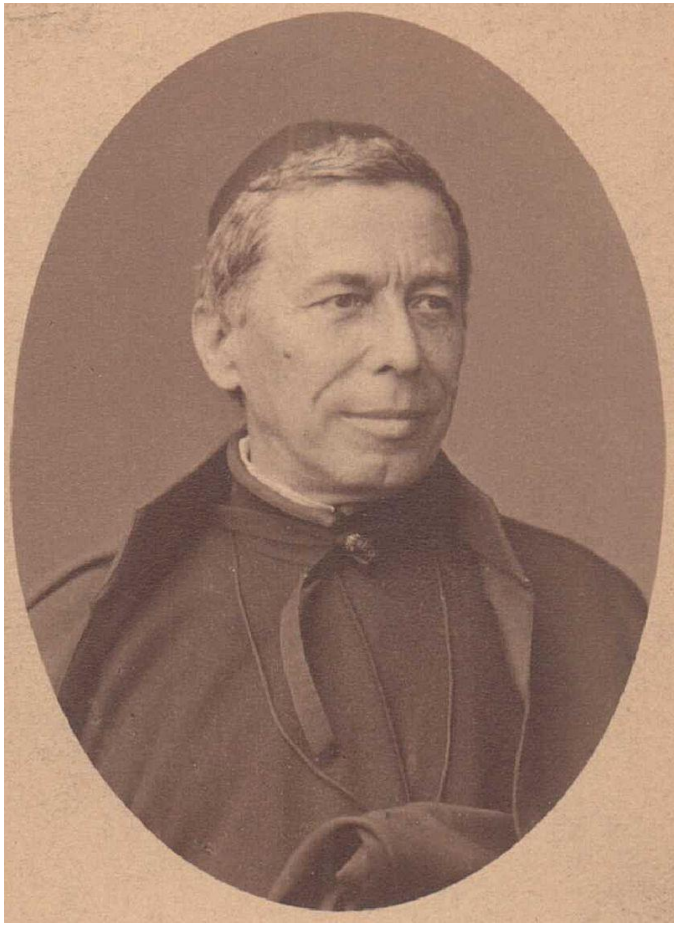
For the Star b.

Mean distance for the beginning of 1838	....	706 ·2909	
Annual variation $= -2''\cdot825 + 0''\cdot2426$	....	−2 ·5824	±0 ·0434
Difference of annual parallax of 61 and b ...	$\beta'' =$	+0 ·2605	±0 ·0278

The observations seem also to indicate, that the difference of the parallaxes of 61 and b is smaller than that of 61 and a; which must be the case, indeed, if b itself have a sensible parallax greater than a. The difference of the computed values of α'' and β'', in fact, exceeds the limits of the probable uncertainty of the observations; but it is to be observed that the probability of *equal* values of α'' and β'' is not so small that we should be inclined to consider the difference of the two as *proved* by the observations. Further observations will increase the weight of both results, and, at the same time, give more accurate values of the annual variations.

I have, therefore, deduced a second result from the observations, which rests on the supposition that the parallaxes of a and b are *insensible*; or that α'' and β'' are equal. For this purpose, since both series must now be brought into connexion with one another, it was necessary to deduce the *weight* of the observations contained in the second series, the weight of those in the first series being taken as unit. I have found it =0·6889; and hence the most probable value of the annual parallax of 61 *Cygni* =0″·3136. On this hypothesis, I find the mean distances of both stars for the beginning of 1838, to be 461″·6171 and 706″·2791; and the corres-

Starting in 1863, Angelo Secchi began collecting the spectra of stars, accumulating some 4,000 stellar spectrograms. Through analysis of this data, he discovered that the stars come in a limited number of distinct types and subtypes, which could be distinguished by their different spectral patterns. From this concept, he developed the first system of stellar classification: the five Secchi classes. The system extended by Annie Jump Cannon to the Harvard one.



General view of the spectra classification criteria

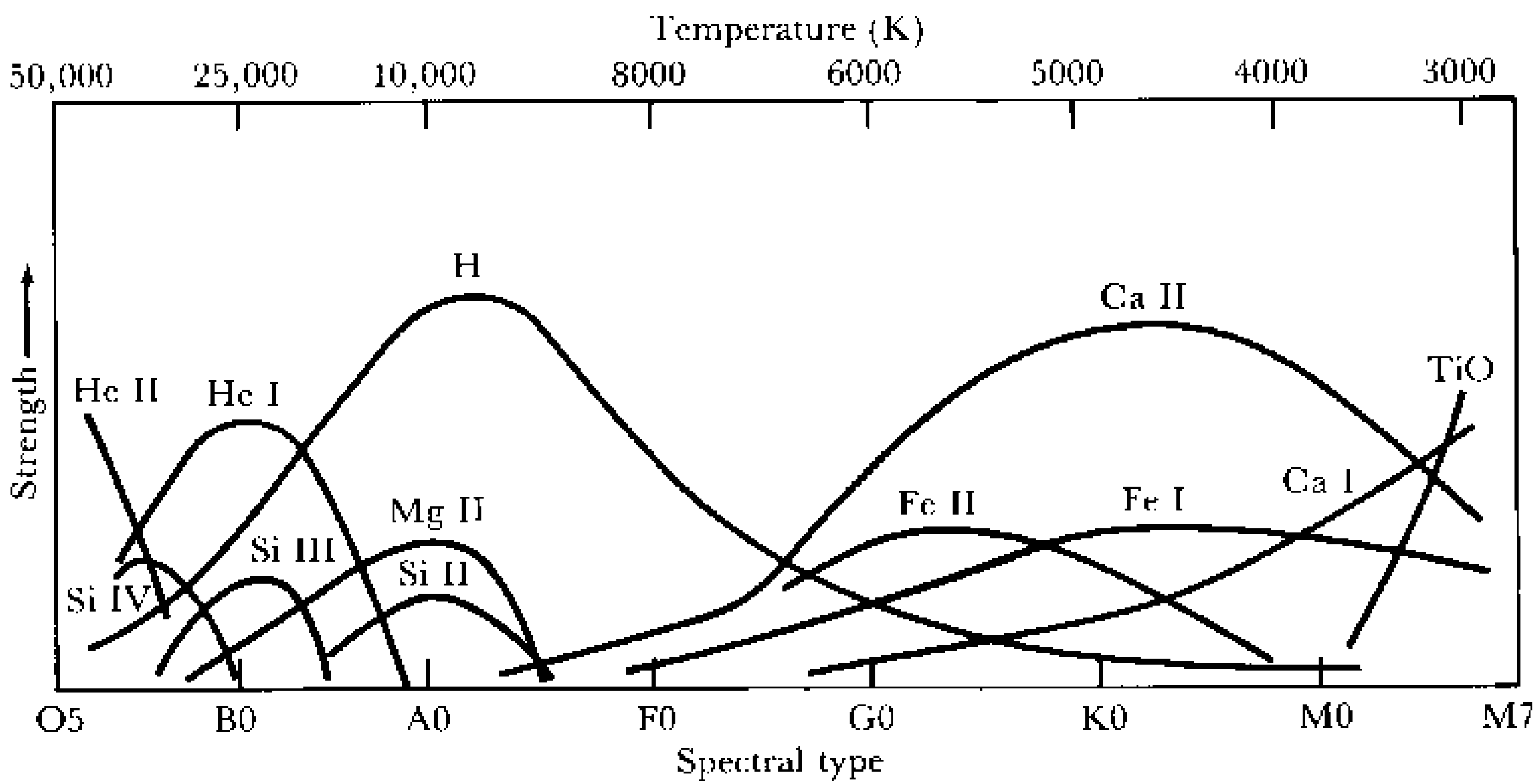
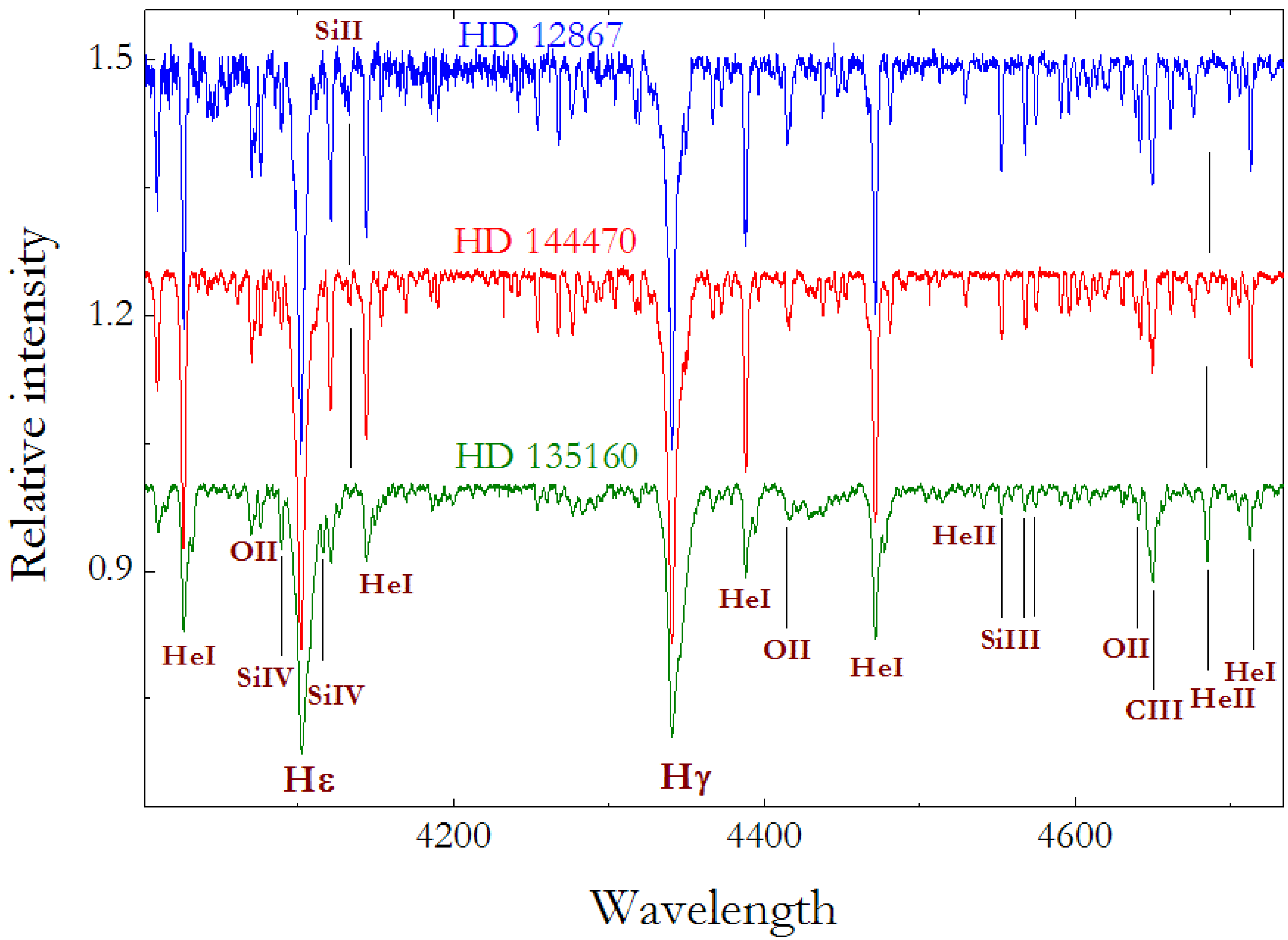


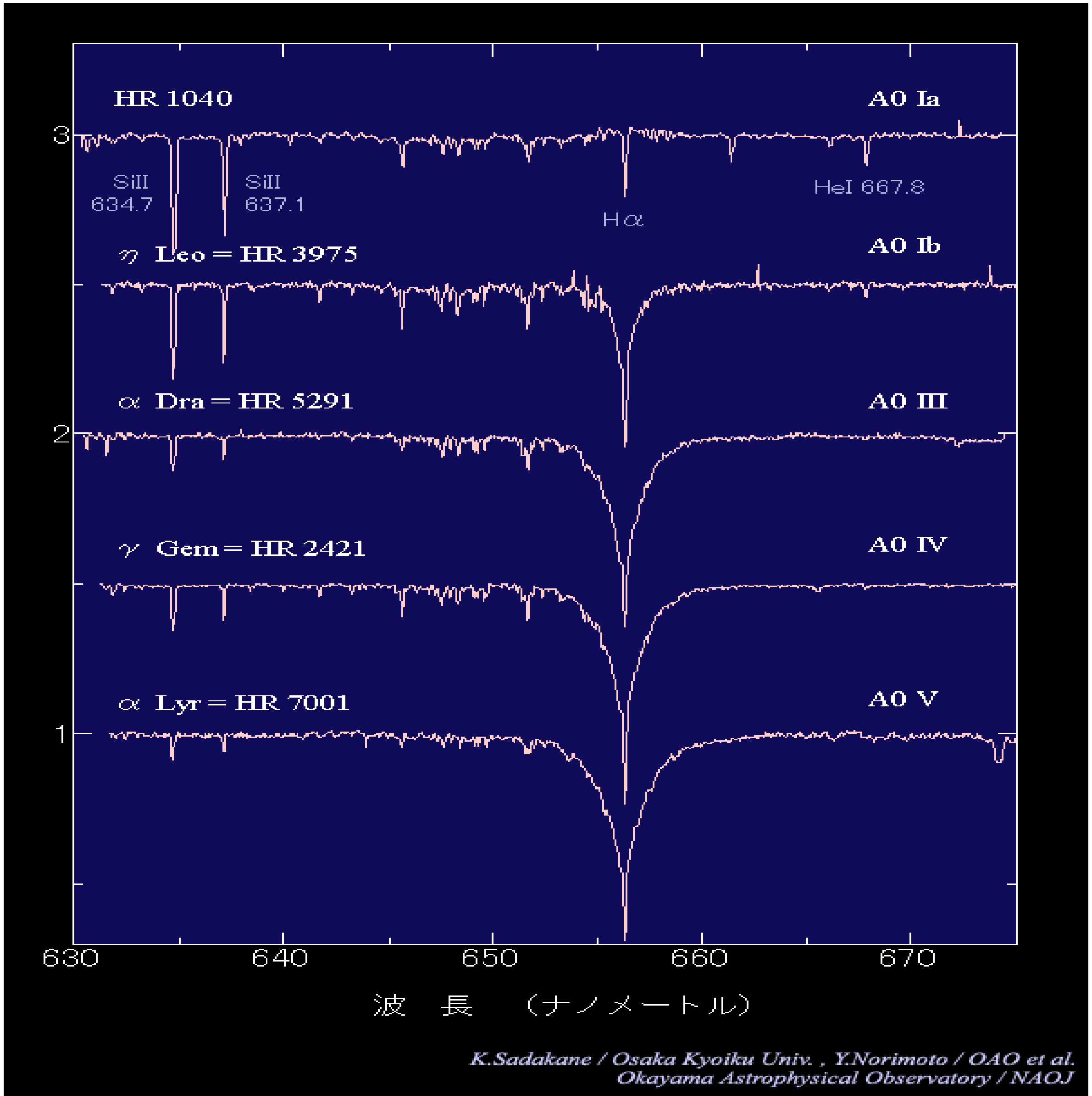
Figure 12-9
Kaufmann
DISCOVERING THE UNIVERSE
Second Edition

T-36

Precise criteria of effective temperature



Variations of the H_α profile with luminosity class

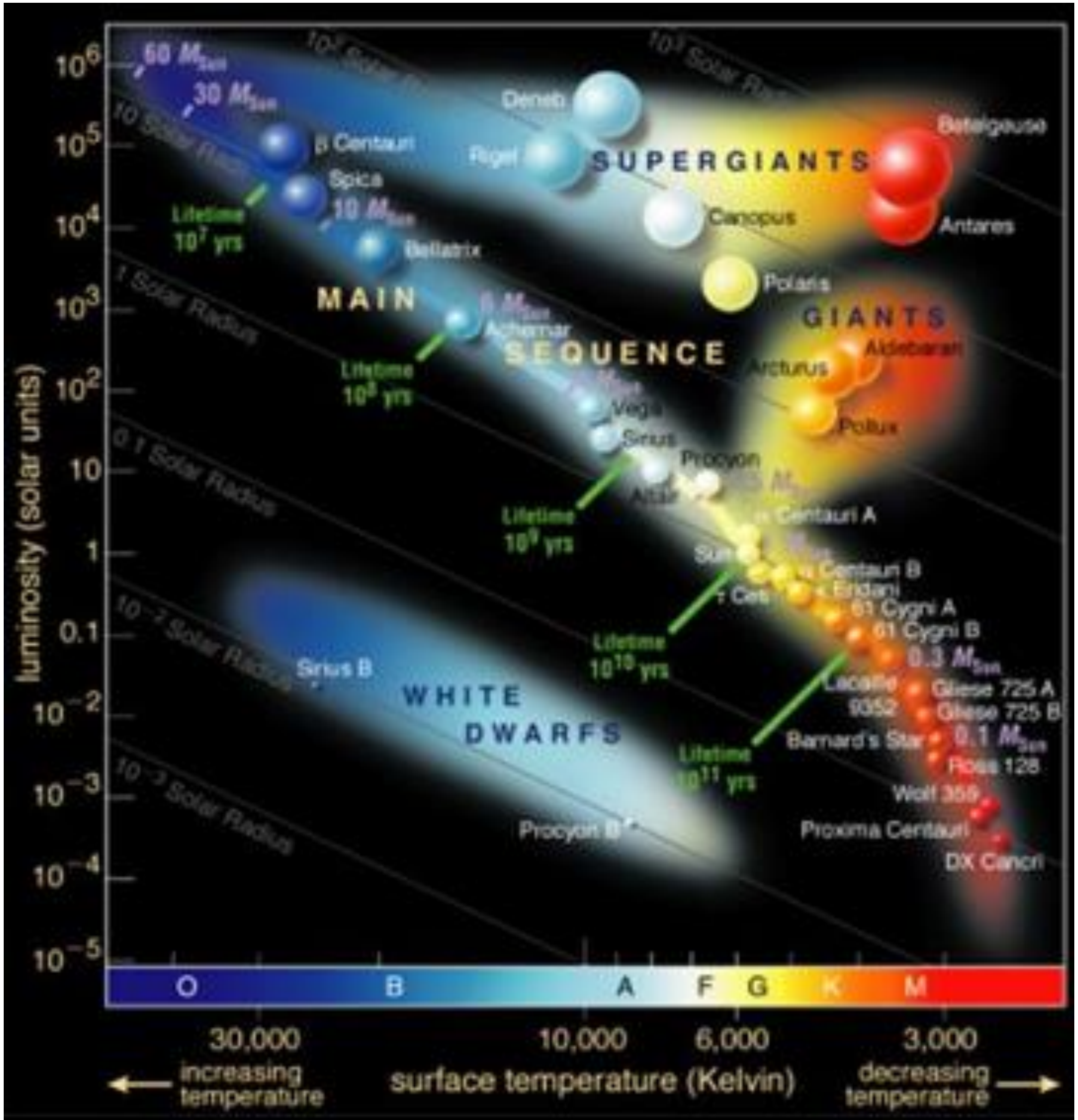


Spectroscopic parallax

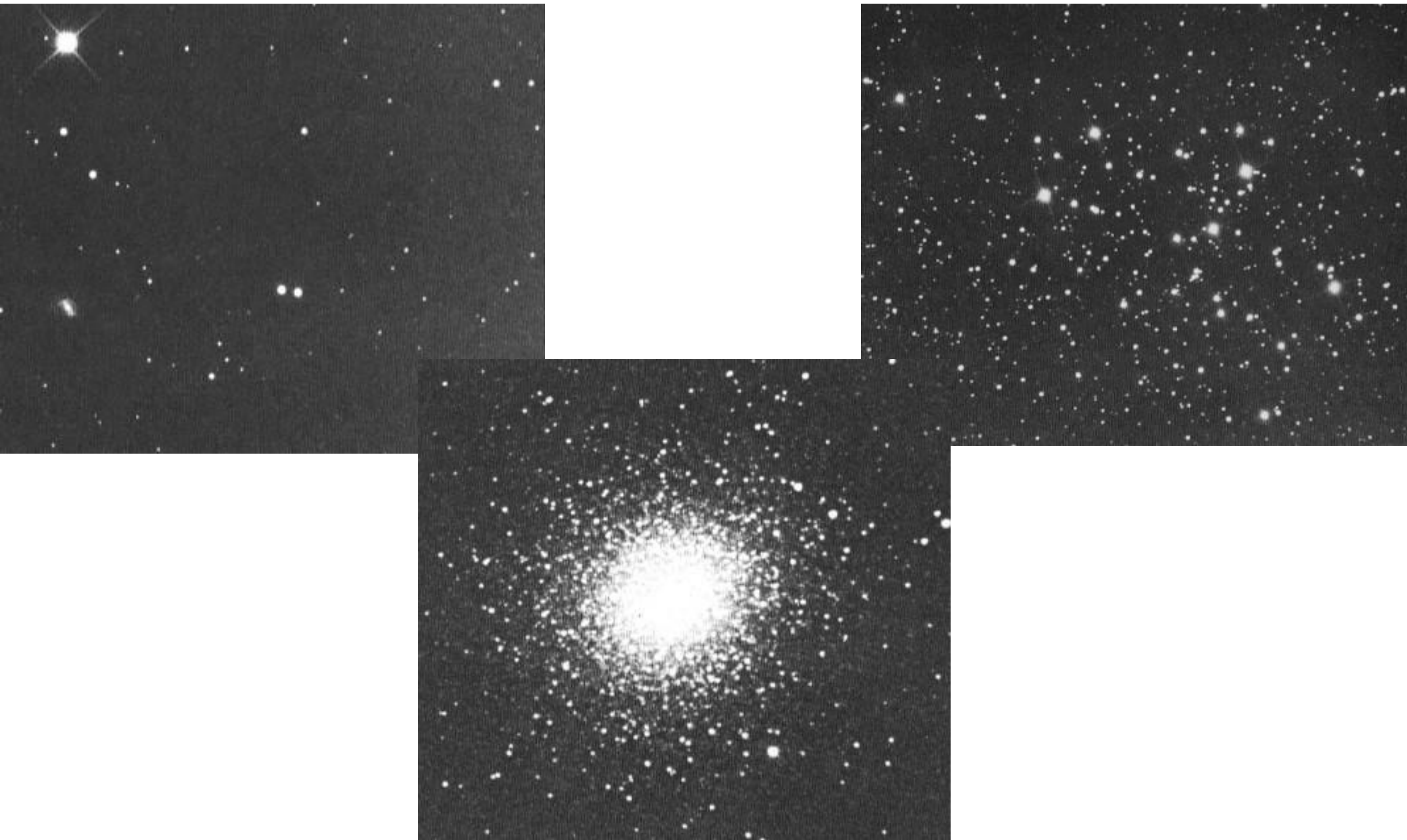
- Assumption: **Sp/L » Mv** (base of stellar astrophysics)
- Distance modulus **m – M = 5logD – 5**
- **m** – direct measurement, **M** – from Sp/L; calibration necessary!
- Assumed: space is empty, i.e. does not attenuate starlight

E. Hertzsprung & H.N. Russell

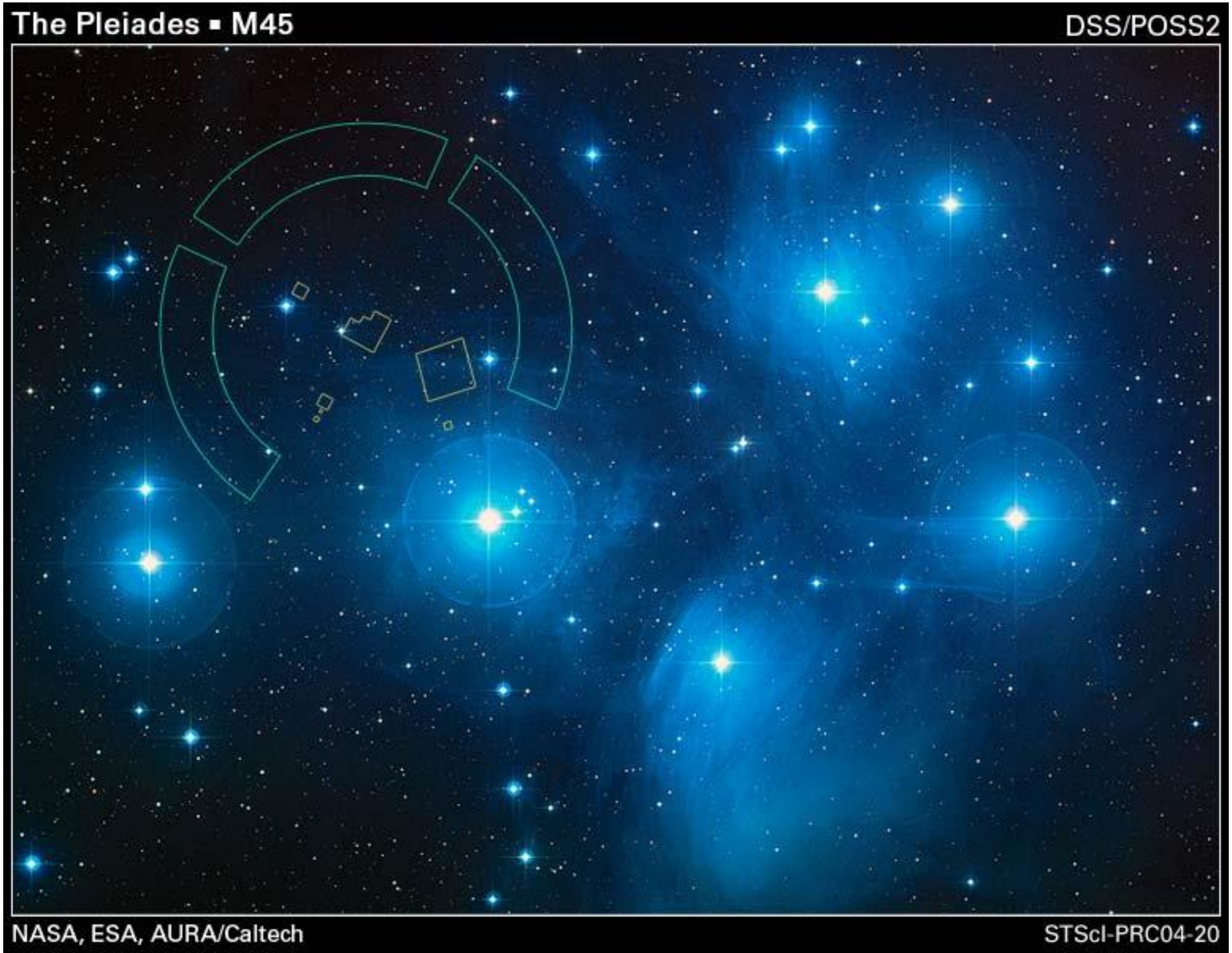
H-R diagram – the product of the second half of XIX century



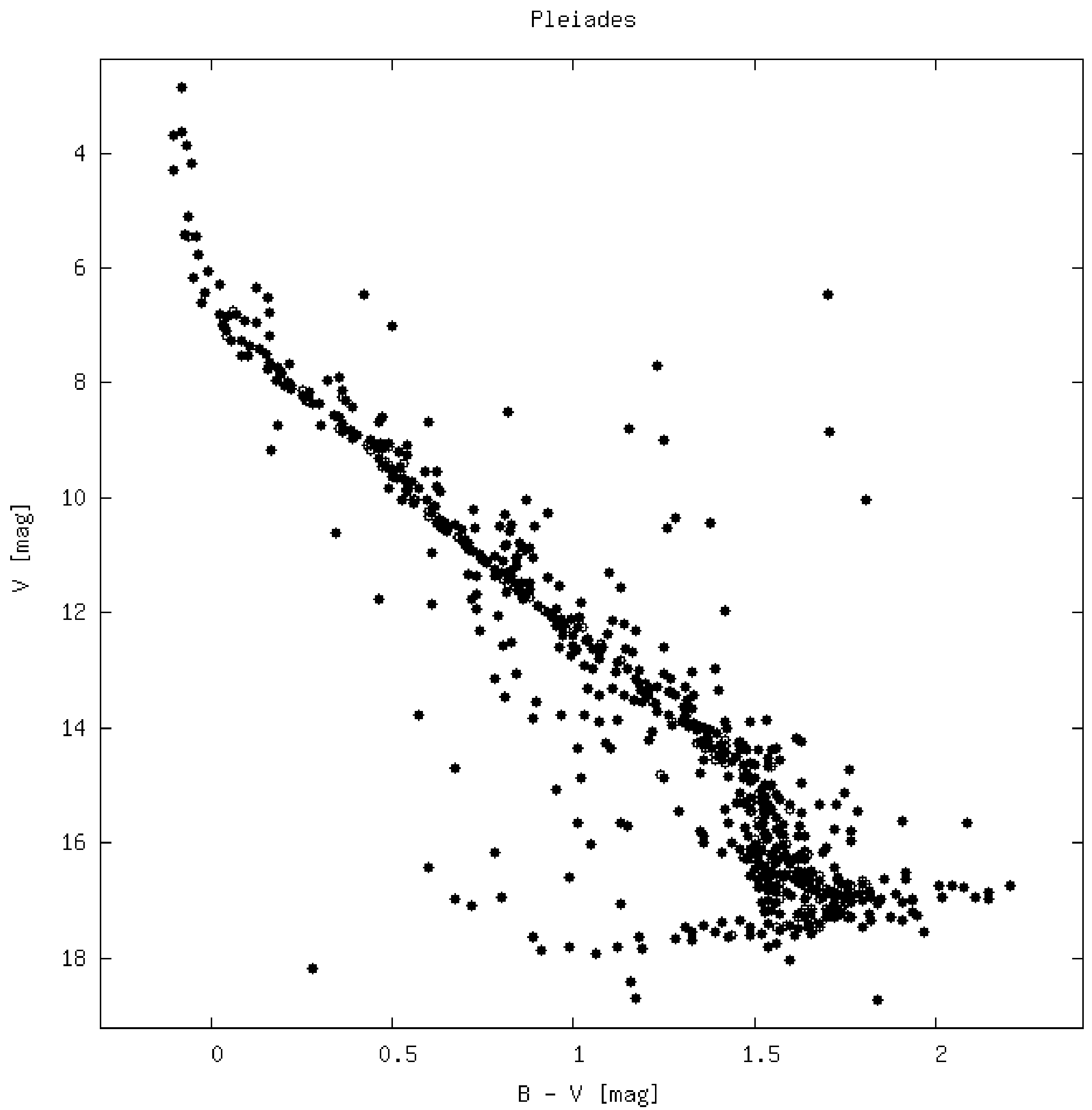
Binary, open cluster and globular cluster



Pleiades – the most widely known open cluster

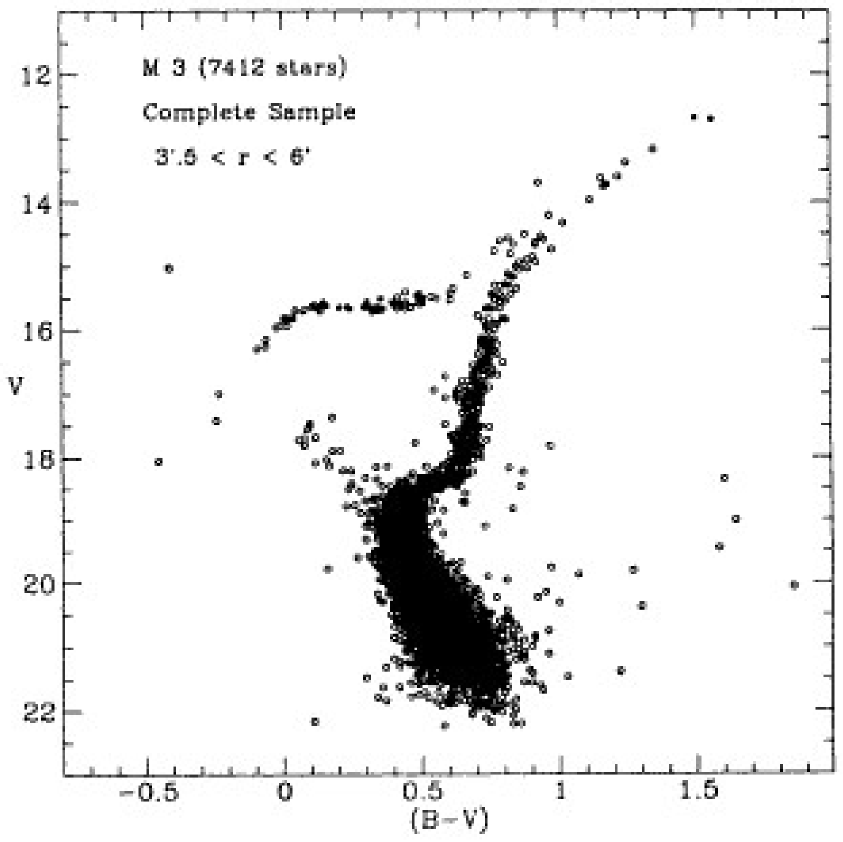


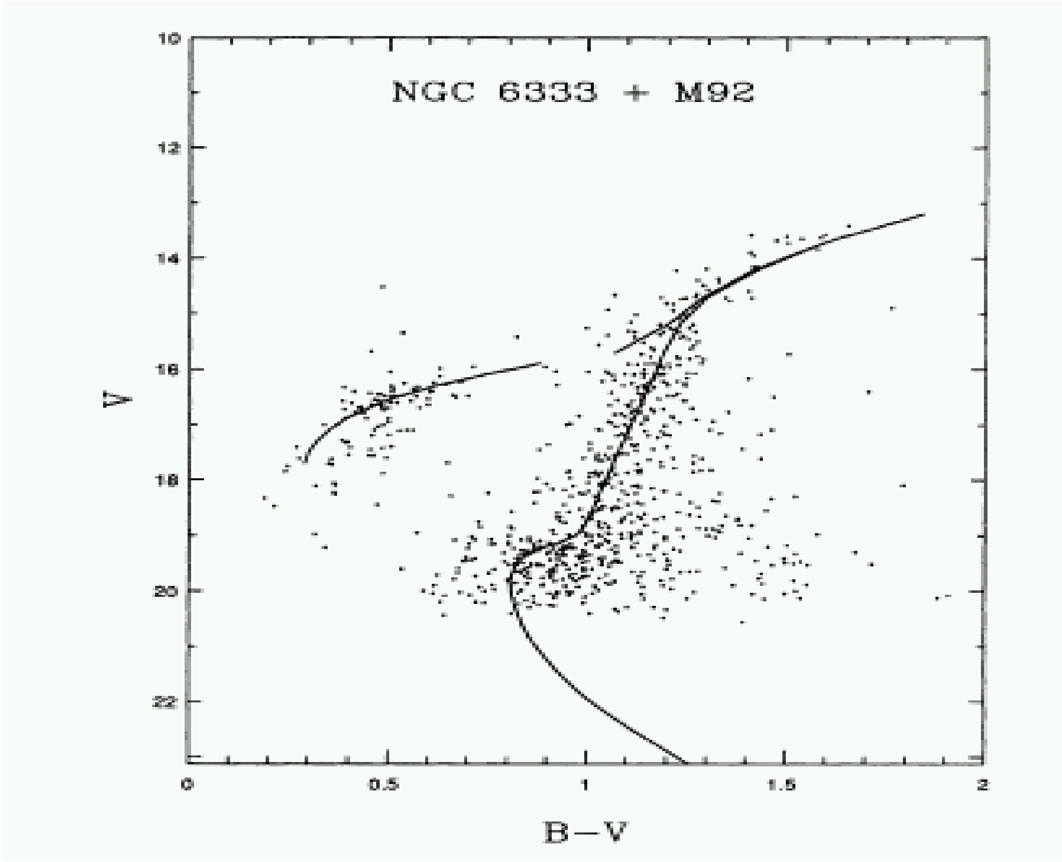
Color-magnitude diagram for Pleiades



Globular clusters M3 and M92

Characteristic HR diagrams for M3 and M92





Absolute stellar magnitudes

- ***Absolute magnitude***, except mass ***is the only extensive parameter***, that allows comparing stars
- ***Photometric equation*** in the general form

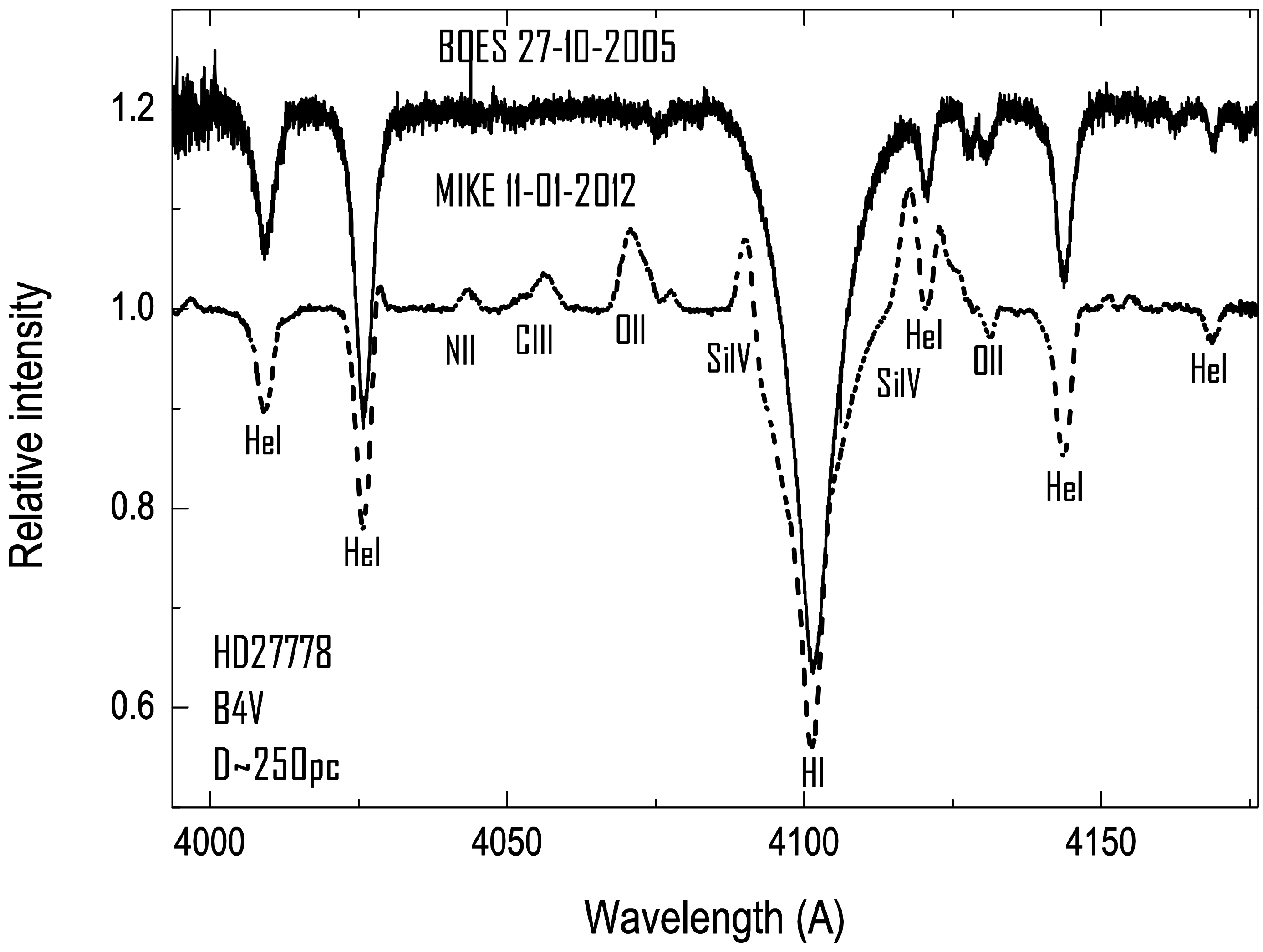
m-M=5logD-5+A,

where ***A*** denotes ***extinction:*** interstellar or intergalactic

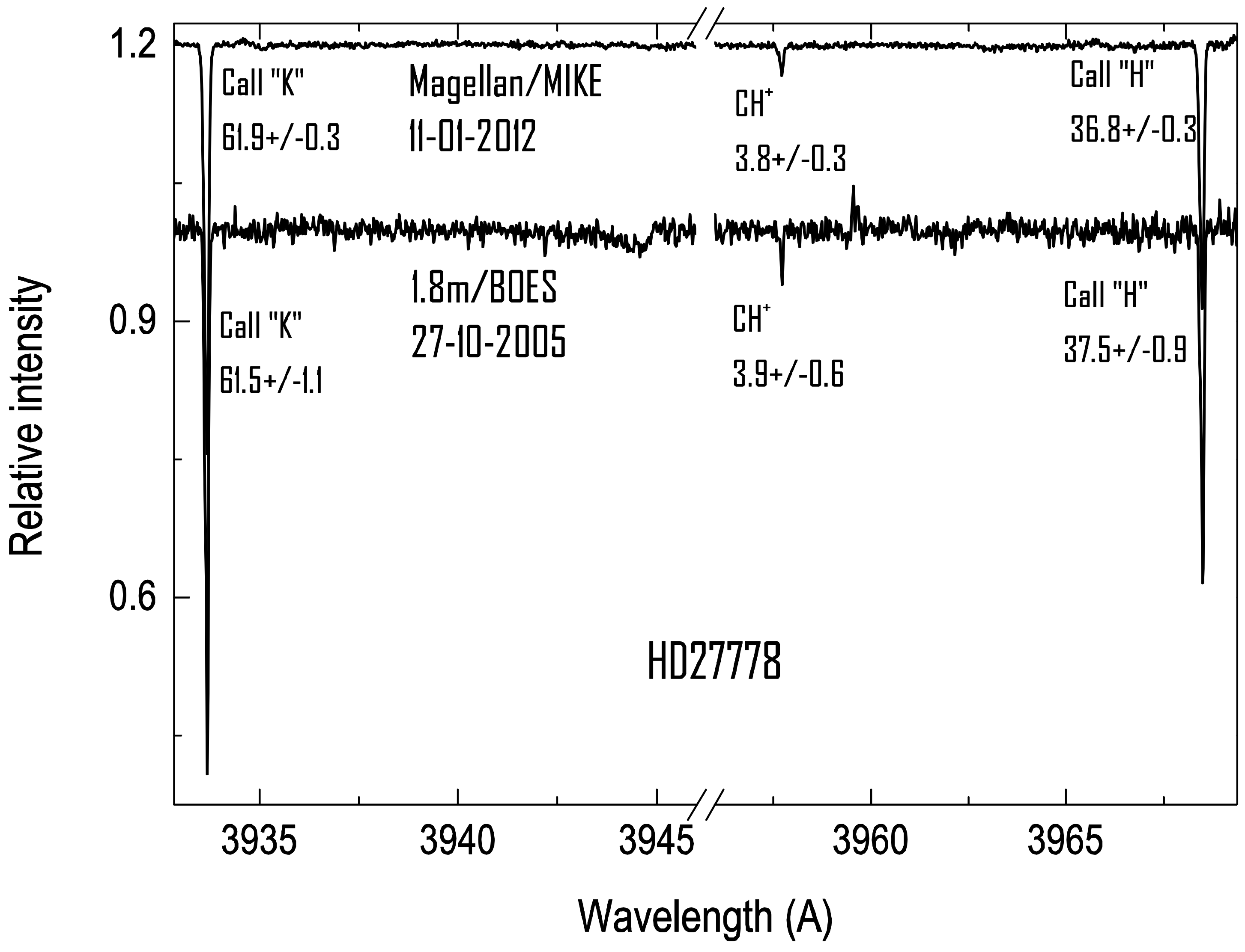
$$A_V = R*E_{B-V}$$

The equation is simple but trappy: it connects parameters which require calibrations.

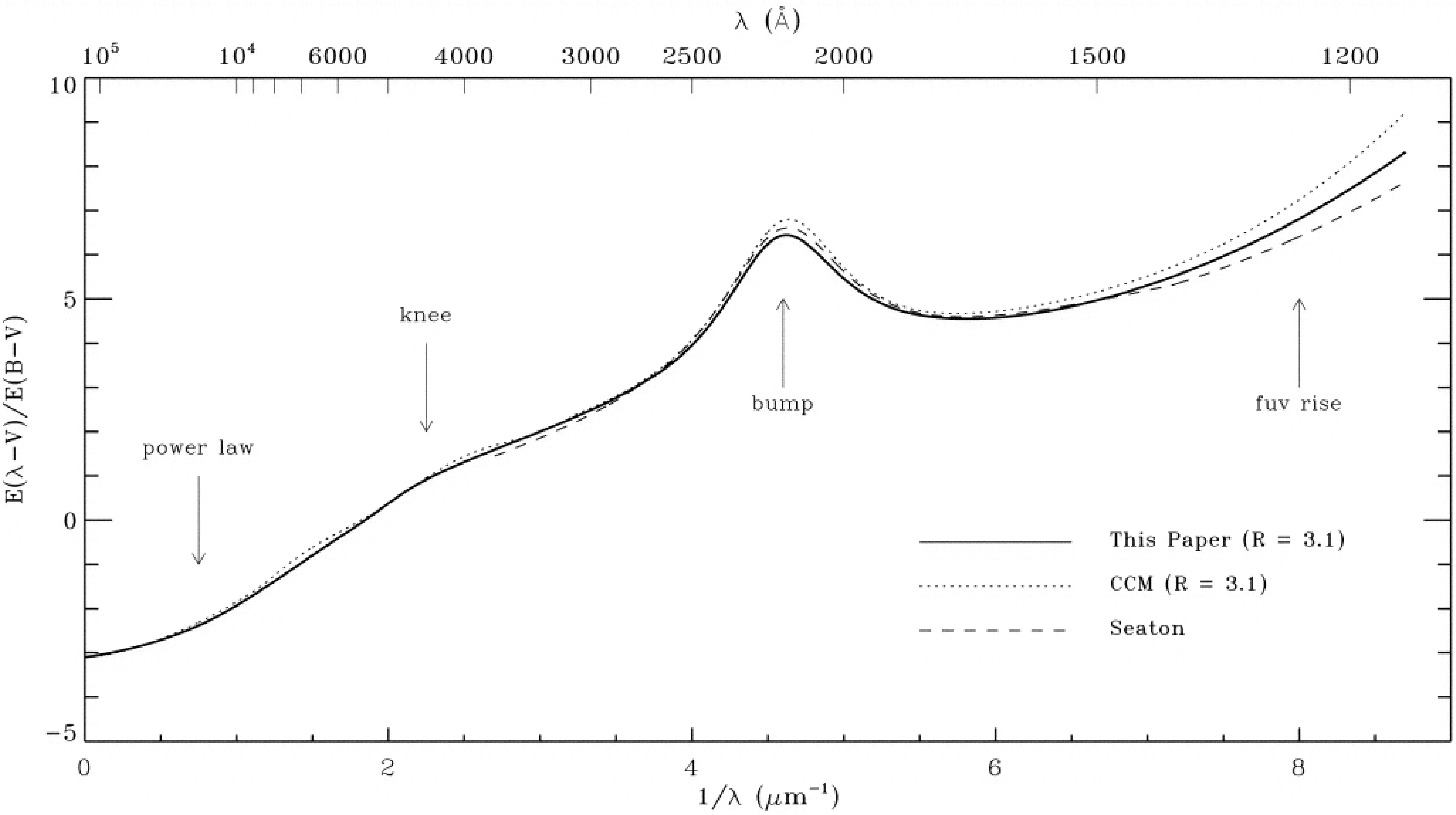
Two spectra of the same star in two epochs. What is its Sp/L?



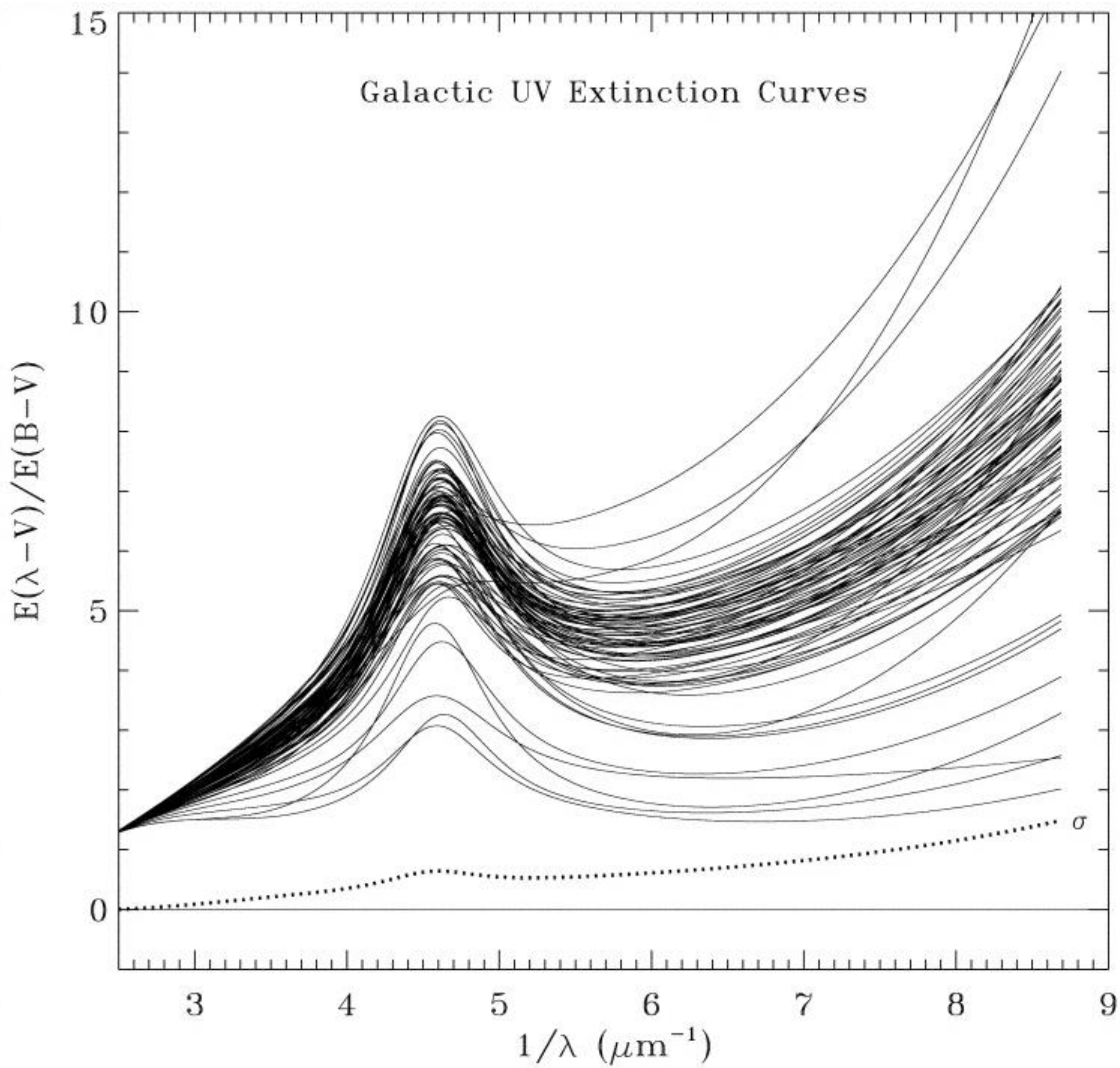
Sp/L may change; interstellar lines remain constant



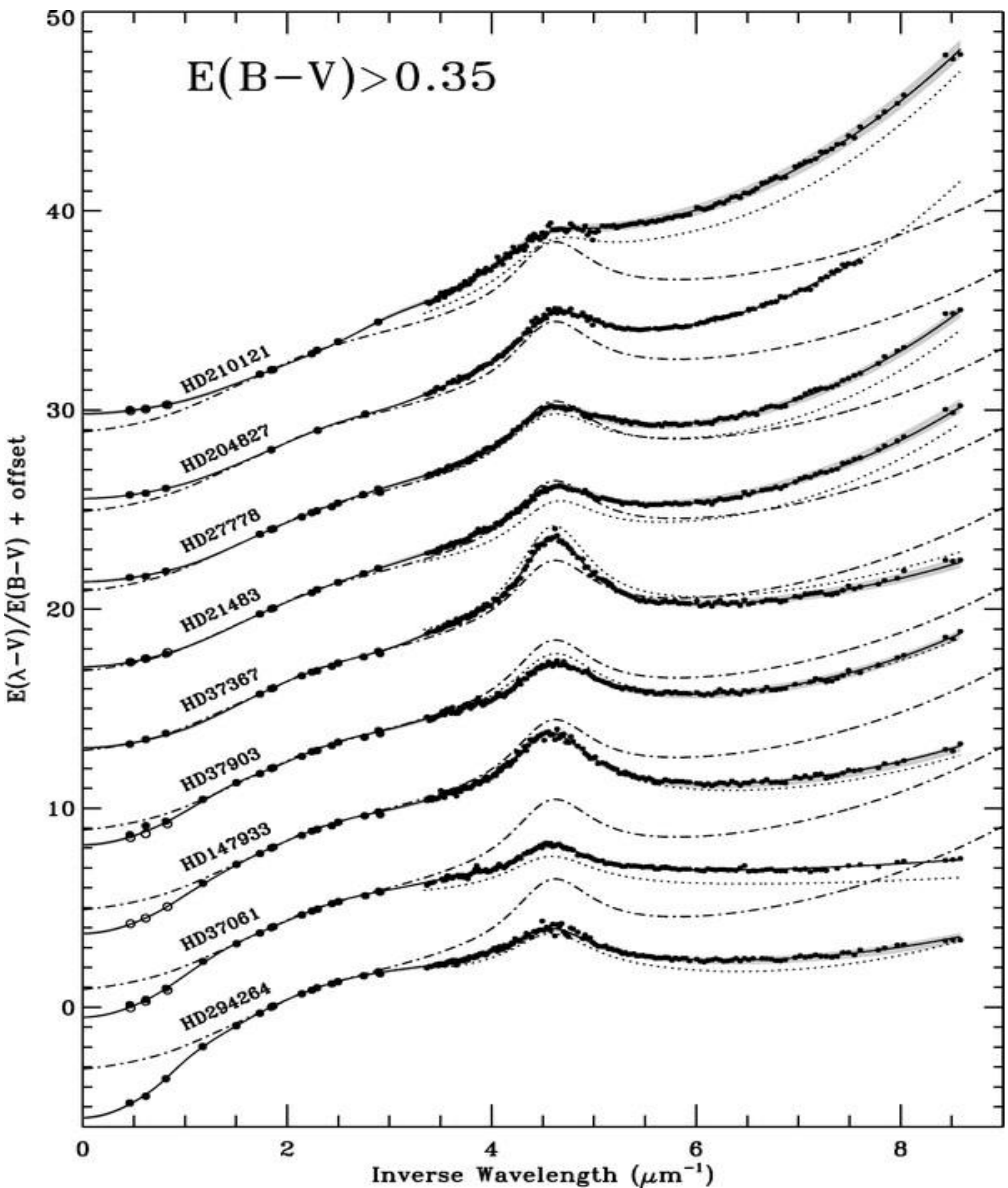
Cardelli, J. A., Clayton, G. C., Mathis, J. S. 1989, ApJ, 345, 245 (CCM89) and Seaton, M. J. 1979, MNRAS, 187, 73



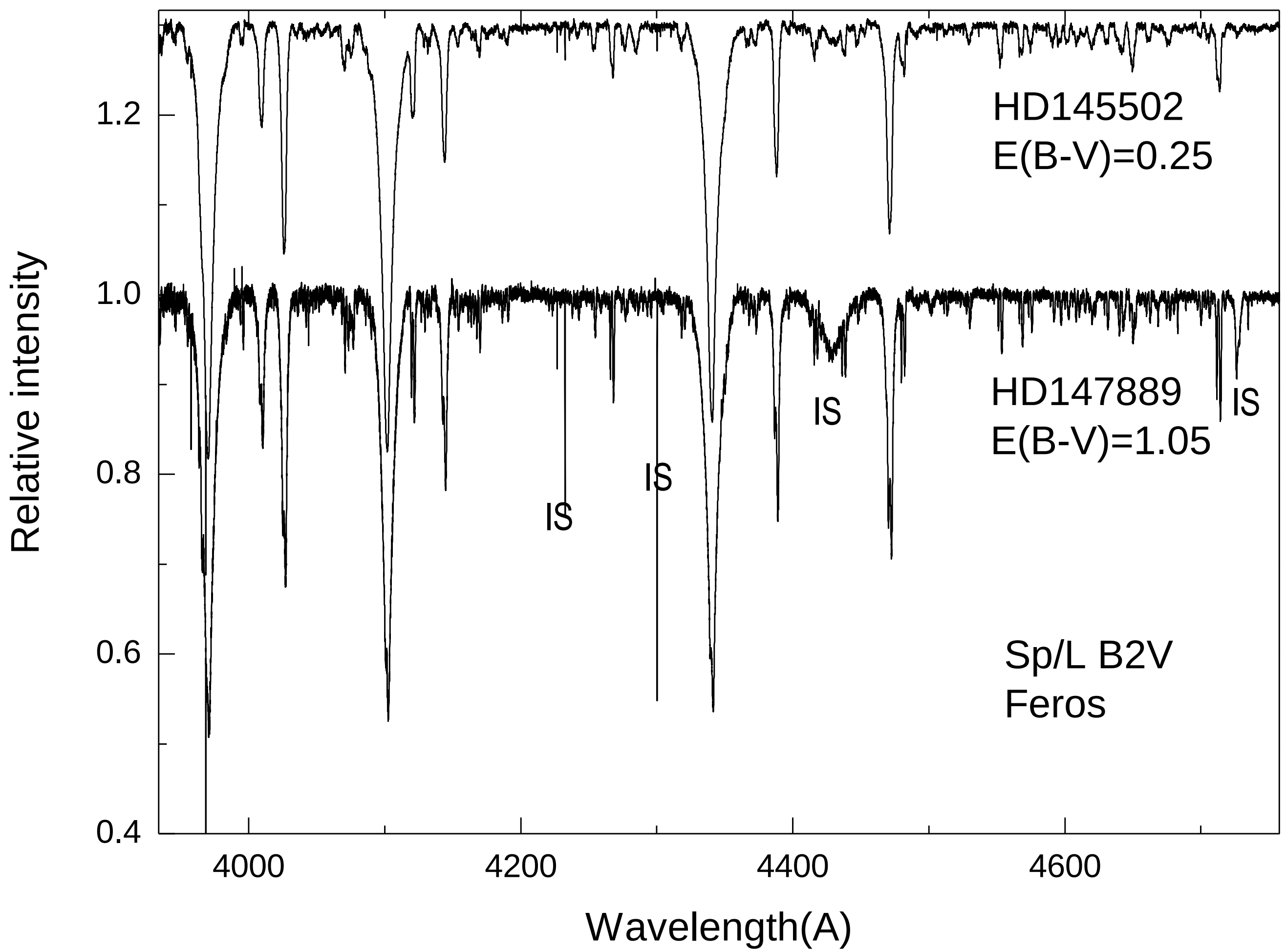
Hard to select a proper individual extinction curve…



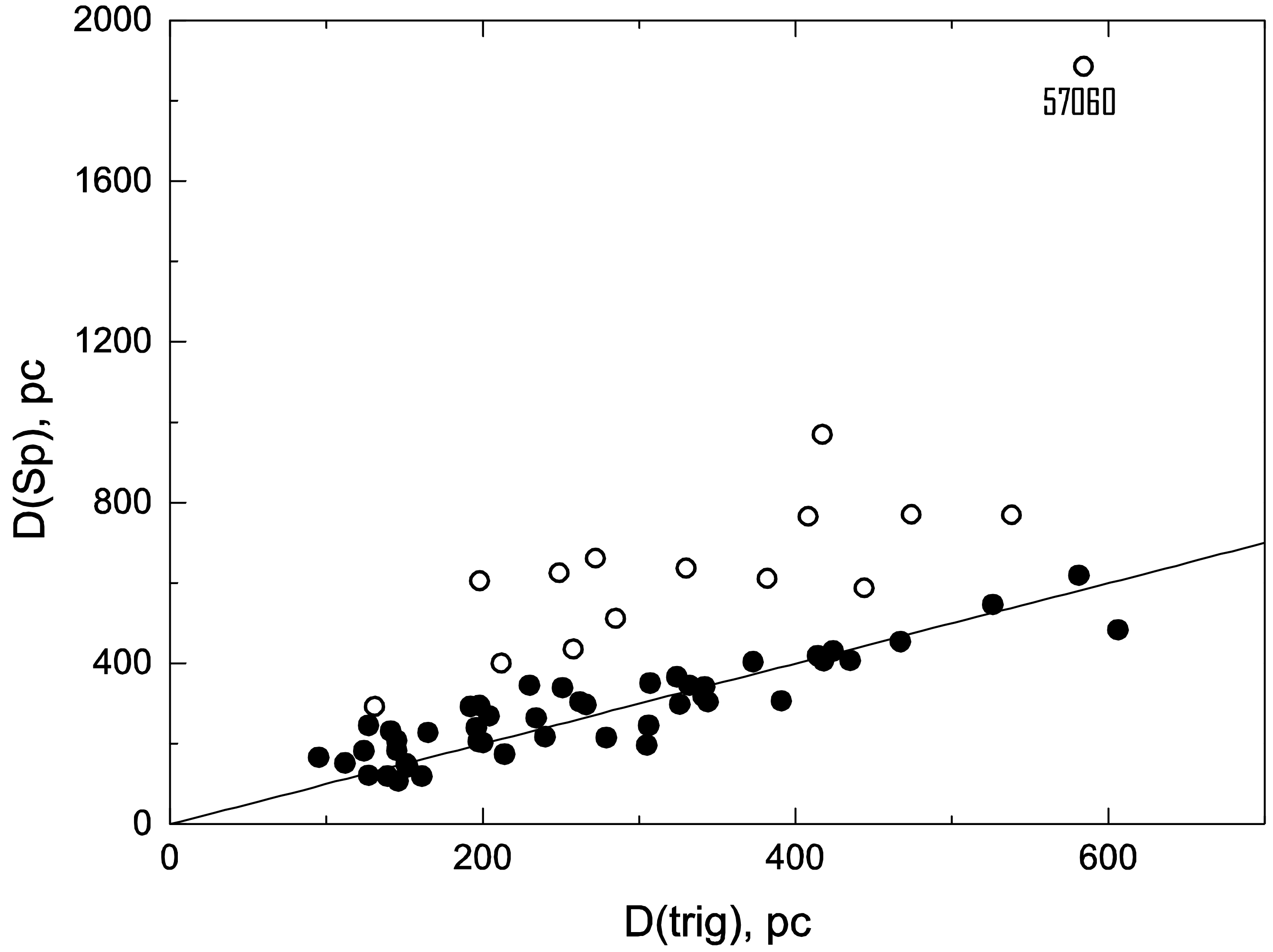
Variety of extinction curves (Fitzpatrick & Massa, 2007)



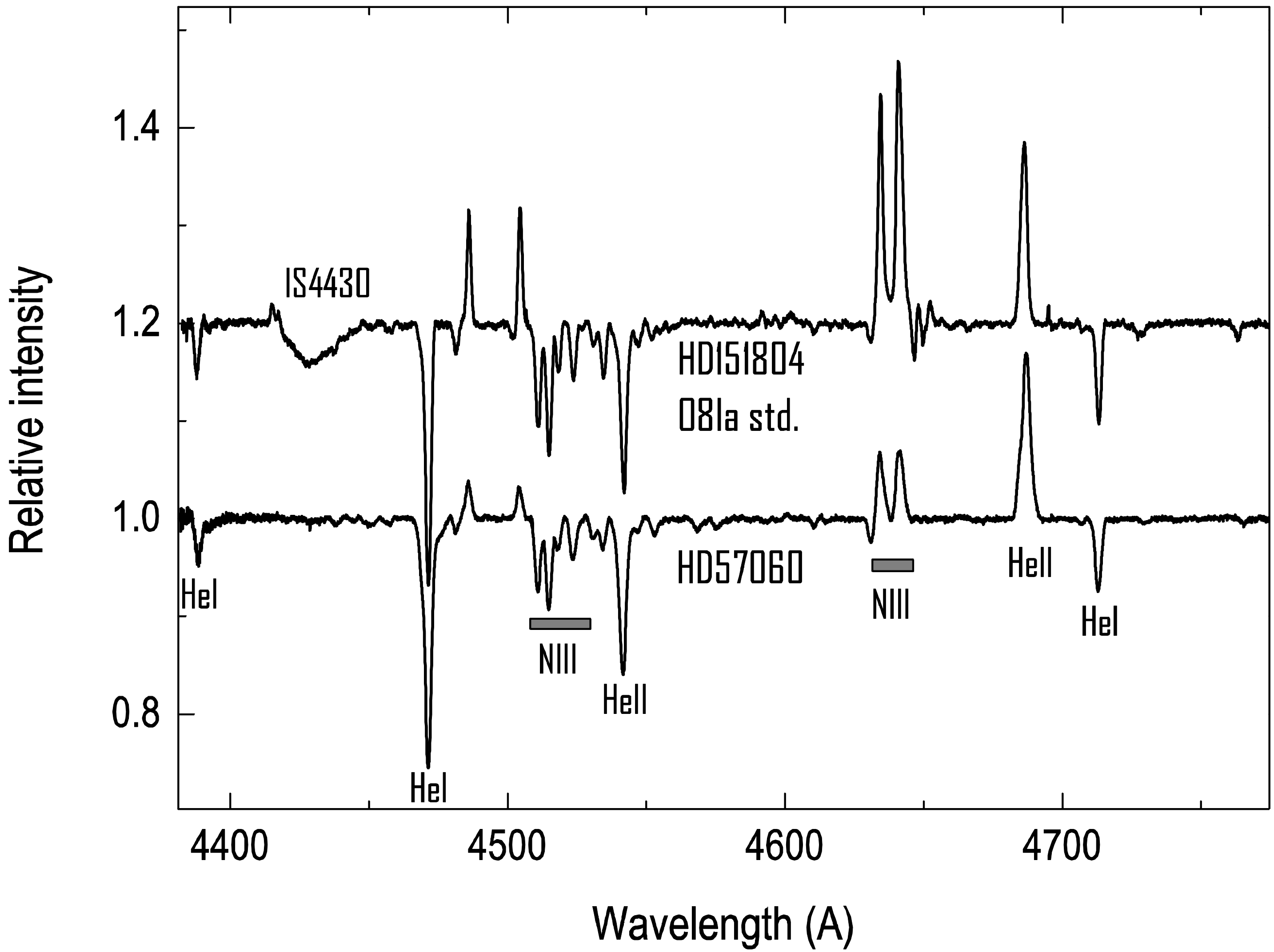
Two identical stars of identical trigonometric parallaxes – 7.5 mas. HD145502 – V=4.00 mag; HD147889 – V=7.90 mag. R=4.9



Some spectrophotometric distances are larger than trigonometric ones



Unreddened HD57060 is of similar Sp/L to O8I standard. If it is O8Ib D=1400 pc.



THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME LXVII JUNE 1928 NUMBER 5

FURTHER WORK ON INTERSTELLAR CALCIUM[1]

By OTTO STRUVE

ABSTRACT

Intensities of the calcium line K have been estimated in 1718 stars of spectral type O–B3, and in 338 stars of later spectral subdivisions. This material has been used for the derivation of systematic errors and for the determination of the precision of such intensity estimates.

After applying all necessary corrections the material was divided into *groups according to spectral type and according to apparent magnitude.* There appears to be a marked *increase in the intensity of detached K for fainter stars, and for earlier spectral types.* Be stars have also stronger calcium lines than absorption B stars. Several groups of *physically connected stars* were investigated separately, but there appears to be no certain evidence that luminosity or spectral type affect the intensity of K. The results were checked by means of the later types, and by means of estimates made on a stellar line in the vicinity of K. The various effects were not present in these instances, and their intensities closely followed the requirements of the theory of ionization.

It was proposed to *neglect all sources affecting the intensity of detached K, save only the distance of the star,* thus putting $I=f(D)$. This relationship was evaluated *graphically* from groups of stars whose distances are known with sufficient precision. It was then used for the derivation of distances and absolute magnitudes of certain other groups of stars. The results derived in this way are so consistent with other methods that *the assumption $I=f(D)$ seems justified.*

In my paper on "Interstellar Calcium,"[2] published last year, I have given an outline of the problem presented by the peculiar lines of ionized calcium in the spectra of the hottest stars. The intensities of the detached lines, discussed at that time, led to a number of in-

Author: Evans, J. W.

Journal: Astrophysical Journal, vol. 93, p.275, 1941

INTERSTELLAR LINE INTENSITIES AND THE DISTANCES OF THE B STARS

JOHN W. EVANS

ABSTRACT

The relations between the intensities of the interstellar D and K lines and the distances of the O and B stars have been determined. Distances derived from the rotational-velocity displacements of the interstellar lines were used. The relations appear to be approximately linear and are represented by the formulae $r = 2.38D$ and $r = 3.00K$. The mean error of an individual distance derived from either of these formulae is about 20 per cent.

A separate study of the stars of large and small color excess confirmed previous conclusions by other investigators that there is no spatial relation between the interstellar atoms and the particles responsible for the photoelectric color excesses.

A comparison of color excess with Joy's coefficient of photographic absorption yielded a value of 7.9 for the ratio Δ_{ph}/E, in good agreement with the value 8.6 predicted by the λ^{-1} law of selective absorption.

The dispersion in the absolute magnitudes of the O and B stars of a given spectral subdivision and line quality was estimated to be $\pm 1\overset{M}{.}3$, which corresponds to a mean error of a factor of nearly two in photometrically calculated distances.

The accurate determination of the distances of individual O and B stars for which we now have accurate color excesses[1] is an important problem in the study of stellar distribution. This paper presents the results of a purely empirical study of the usefulness of interstellar line intensities as a means for measuring distance. The theory of line absorption has not been considered. It differs from most previous investigations of this problem[2, 3, 4, 5, 6] in that accurate, photometrically measured line intensities are calibrated by means of geometrically determined distances, free from the errors arising from uncertainties in space absorption and absolute magnitudes which are inherent in photometric distance measurements.

For the sake of brevity and continuity in the discussion all definitions of symbols are

Possibility to improve the ancient idea

Published measurements of triginometric parallaxes by the satellite Hipparcos (10 times more precise than groundbased ones)

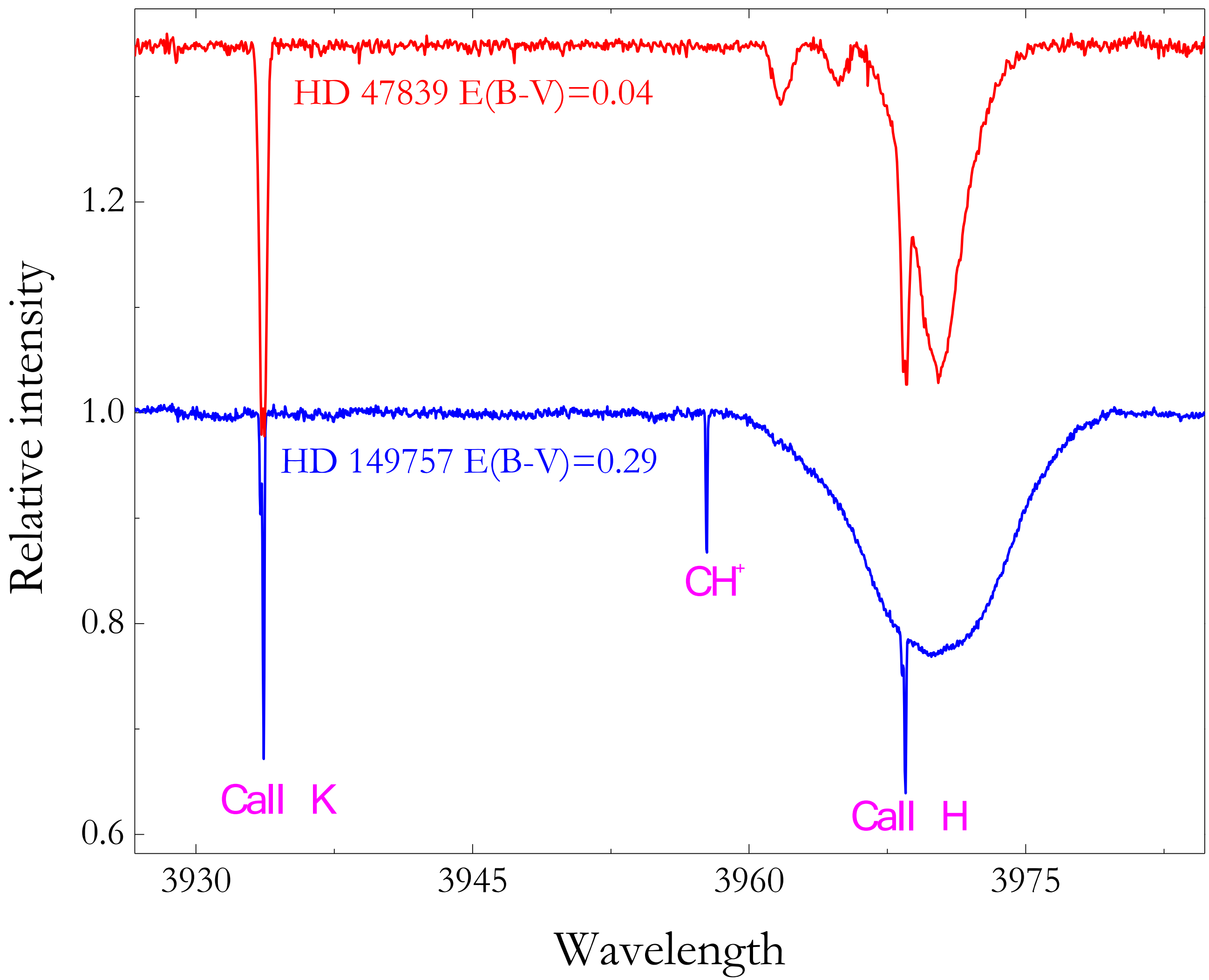
The set of high resolution and S/N echelle spectra

which allow

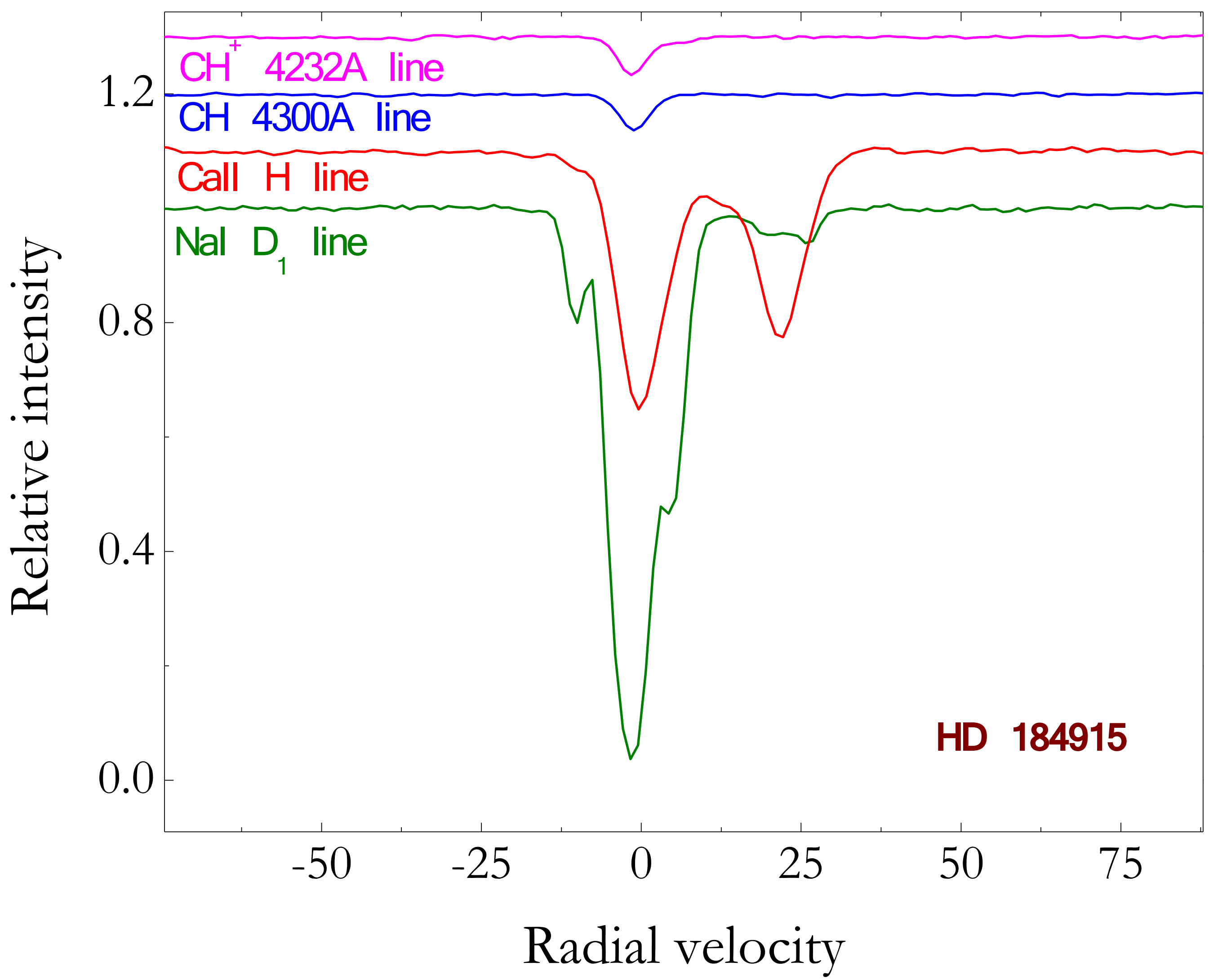
Simultaneaous measurements of many interstellar features

290 objects with known trigonometric parallax

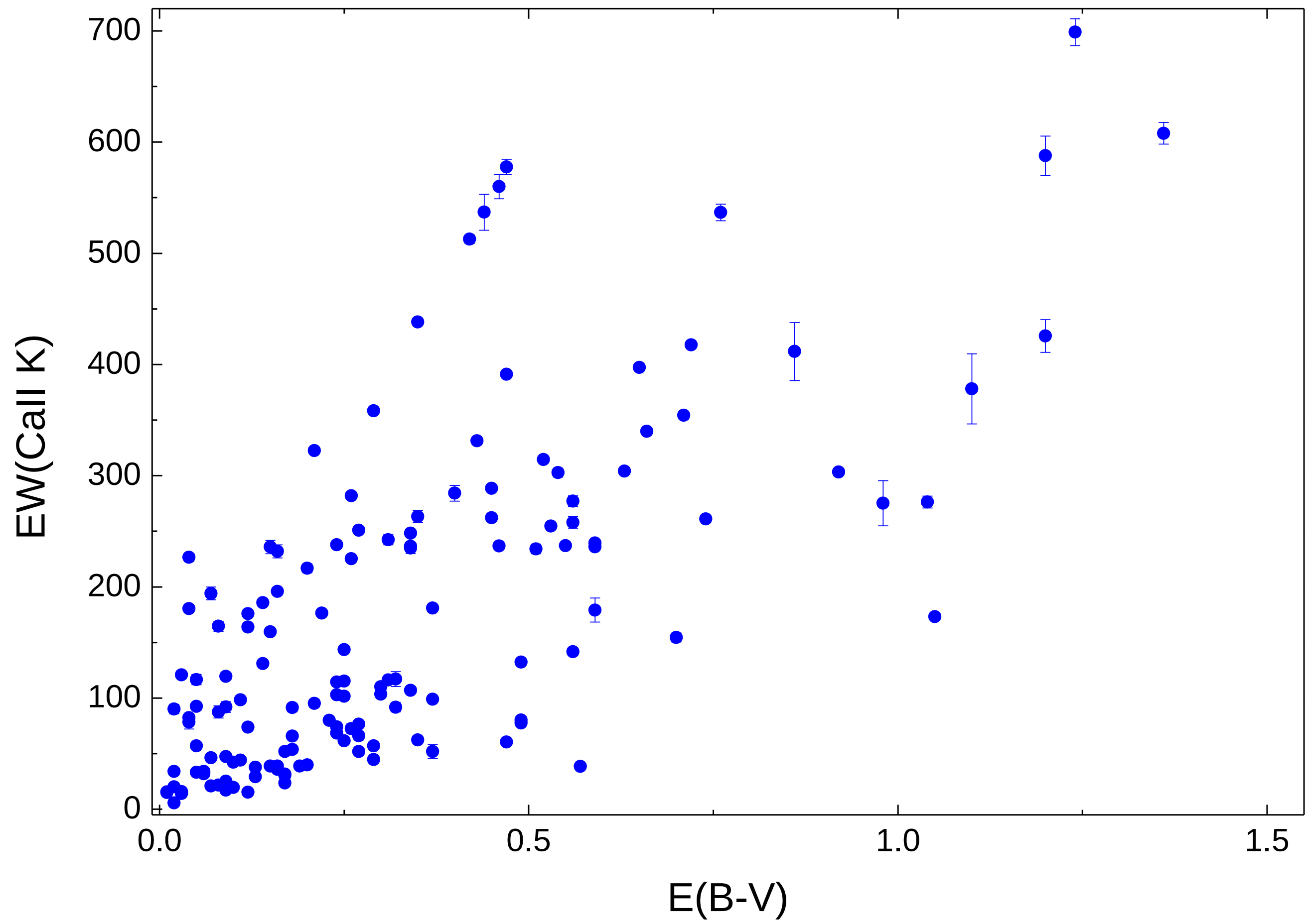
CaII interstellar lines are observed alone



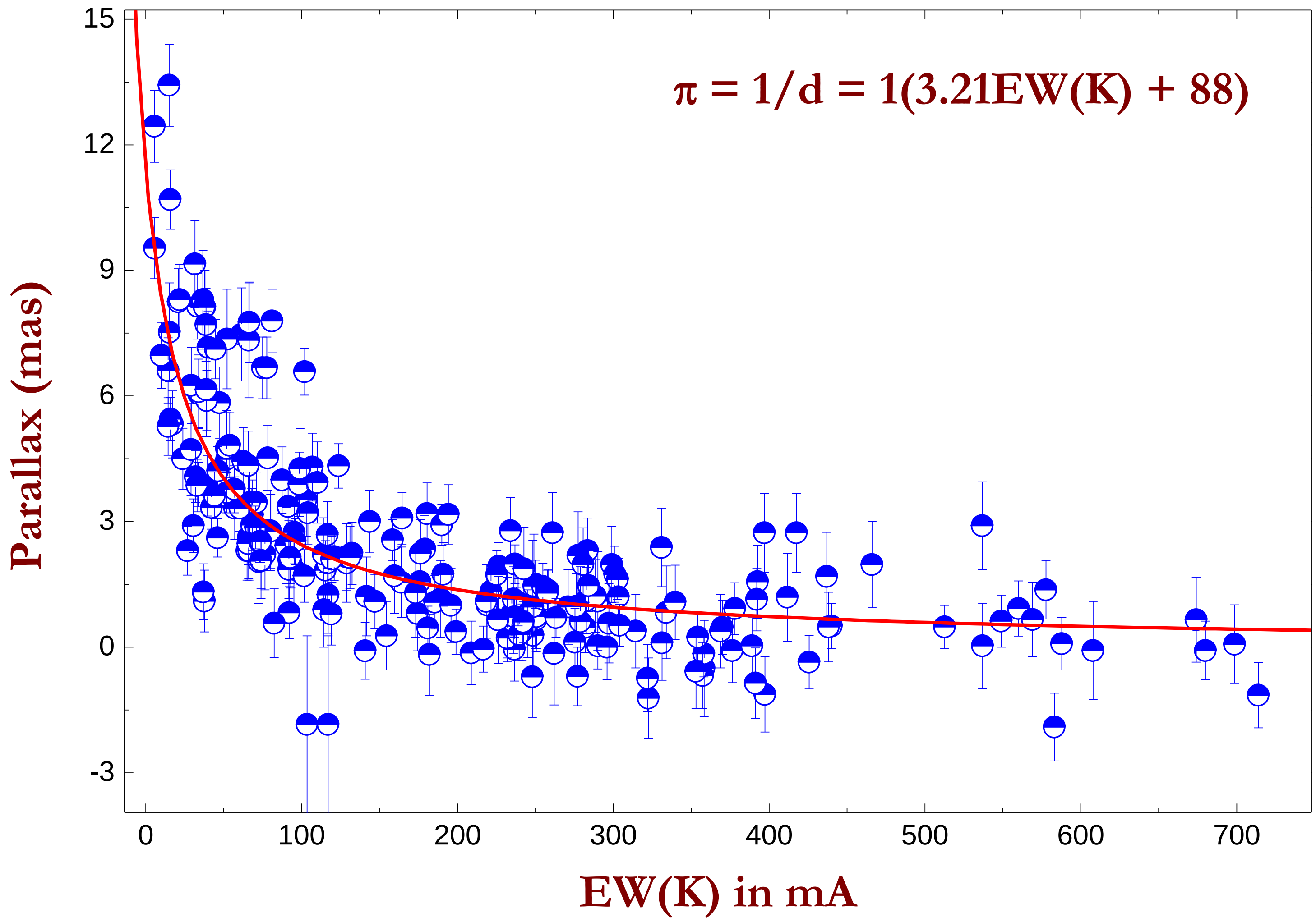
Additional evidence



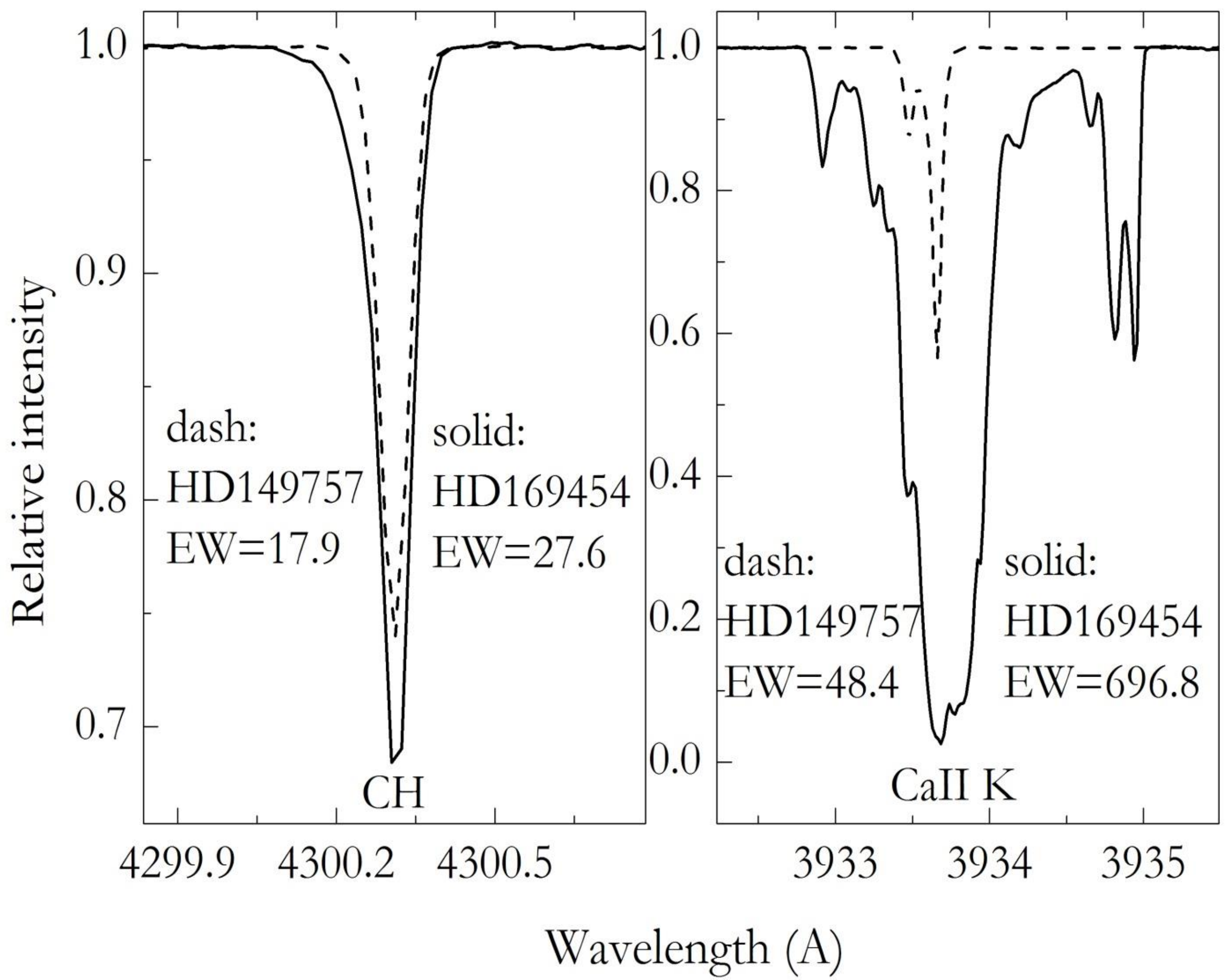
Lack of correlation between E(B–V) and equivalent width of the CaII „K" line



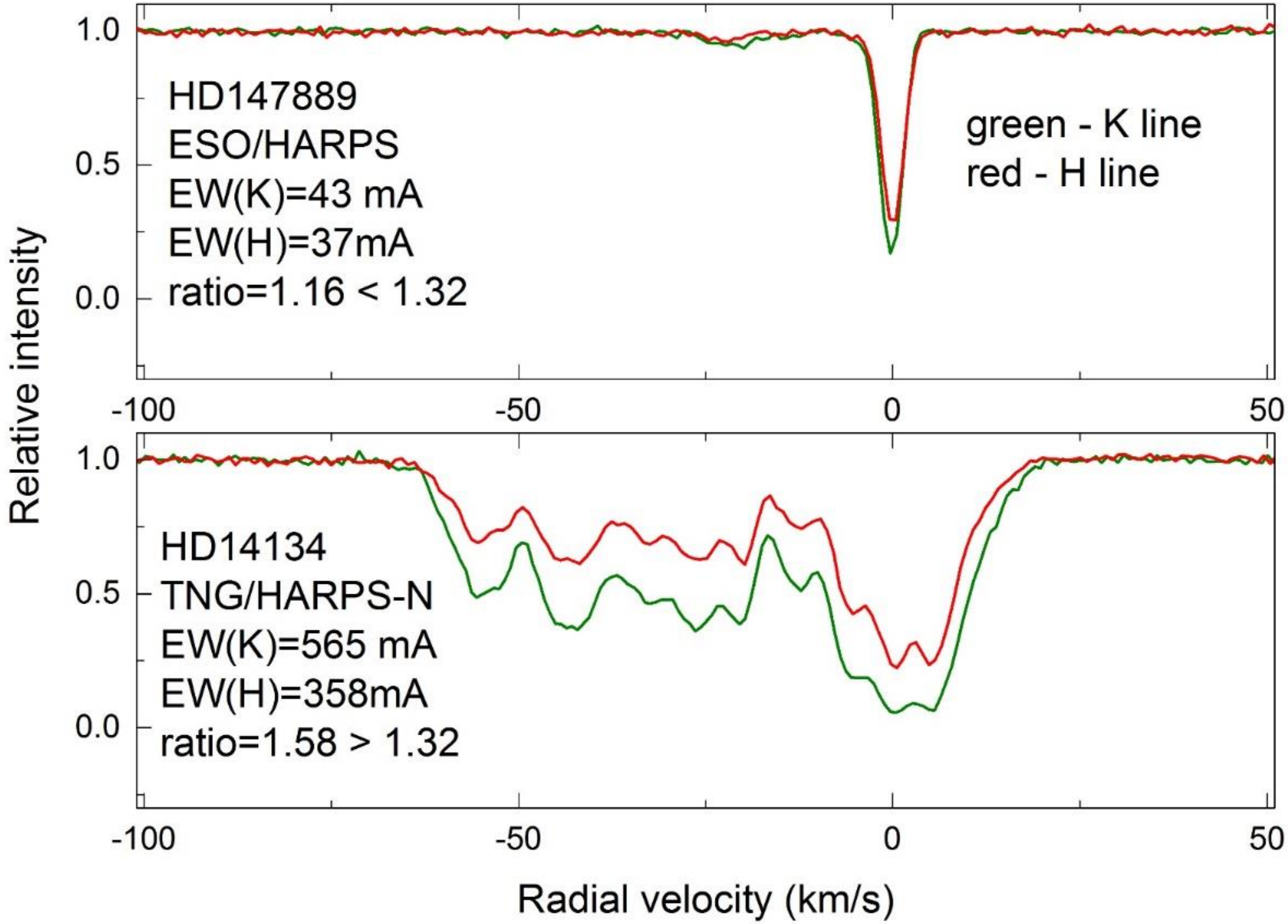
Correlation between Hipparcos parallax and EW(K)



CaII is evenly distributed in contrary to CH

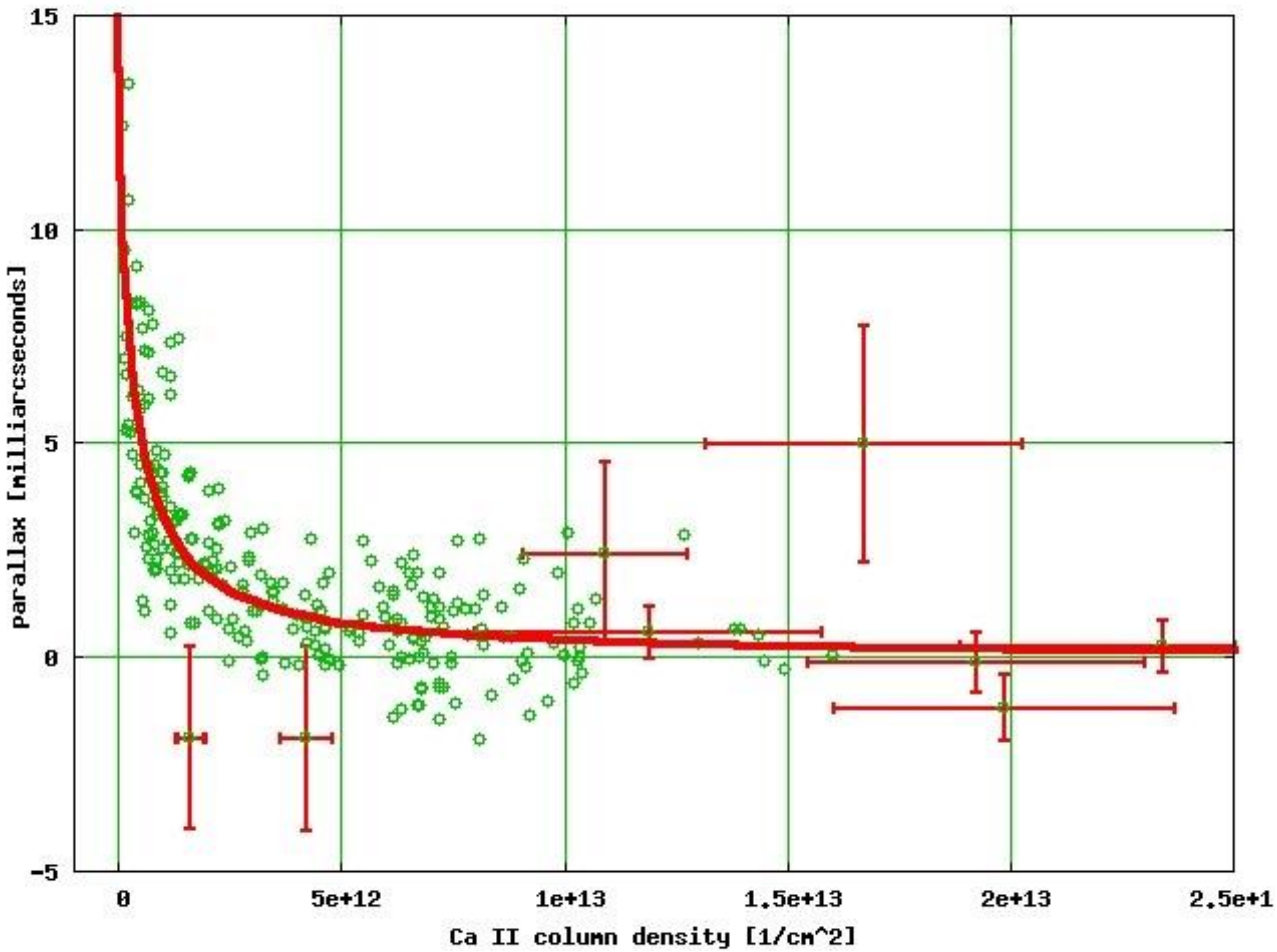


Lines H i K in spectra of nearby and distant stars l=135

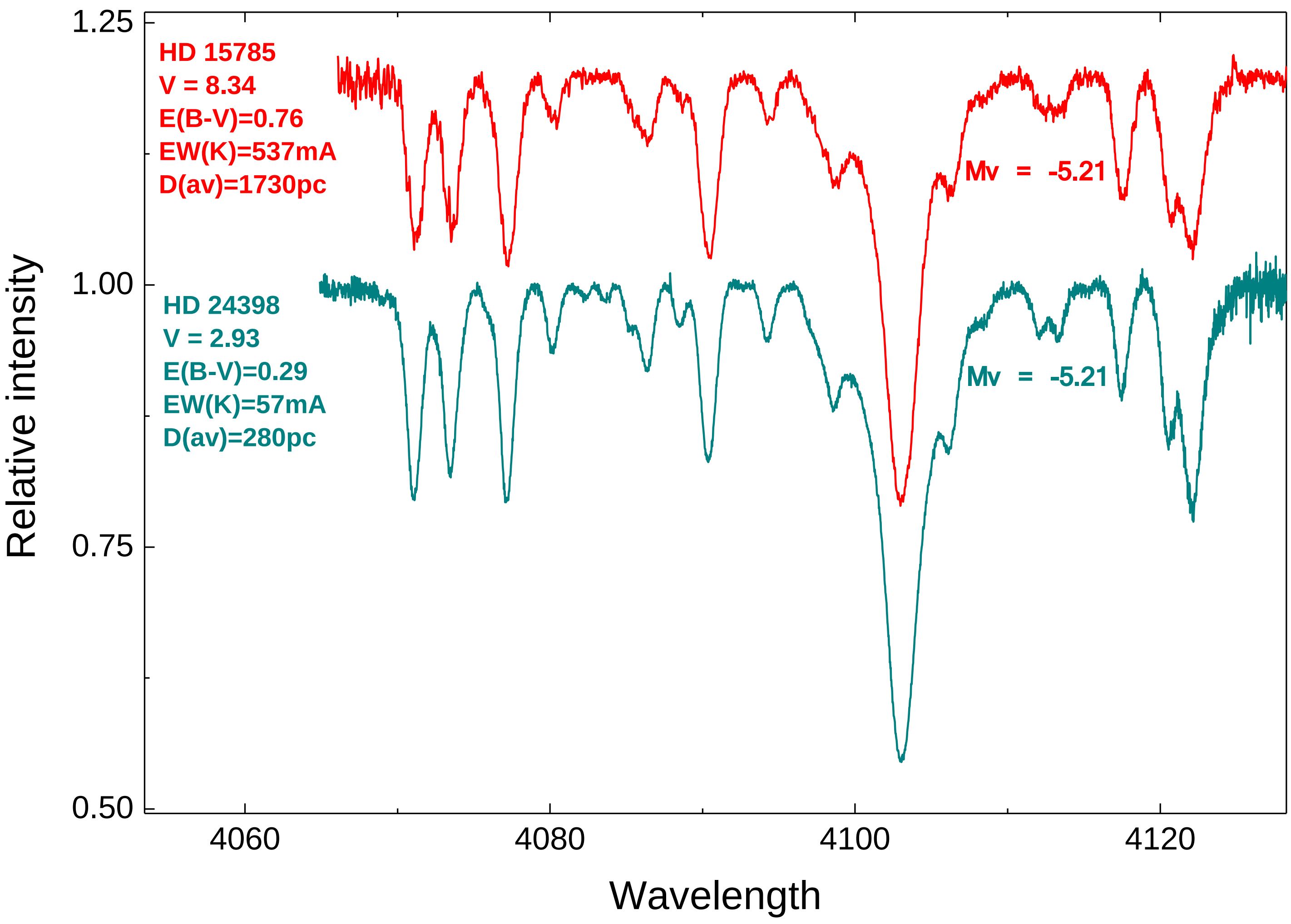


Column density of CaII vs. distance

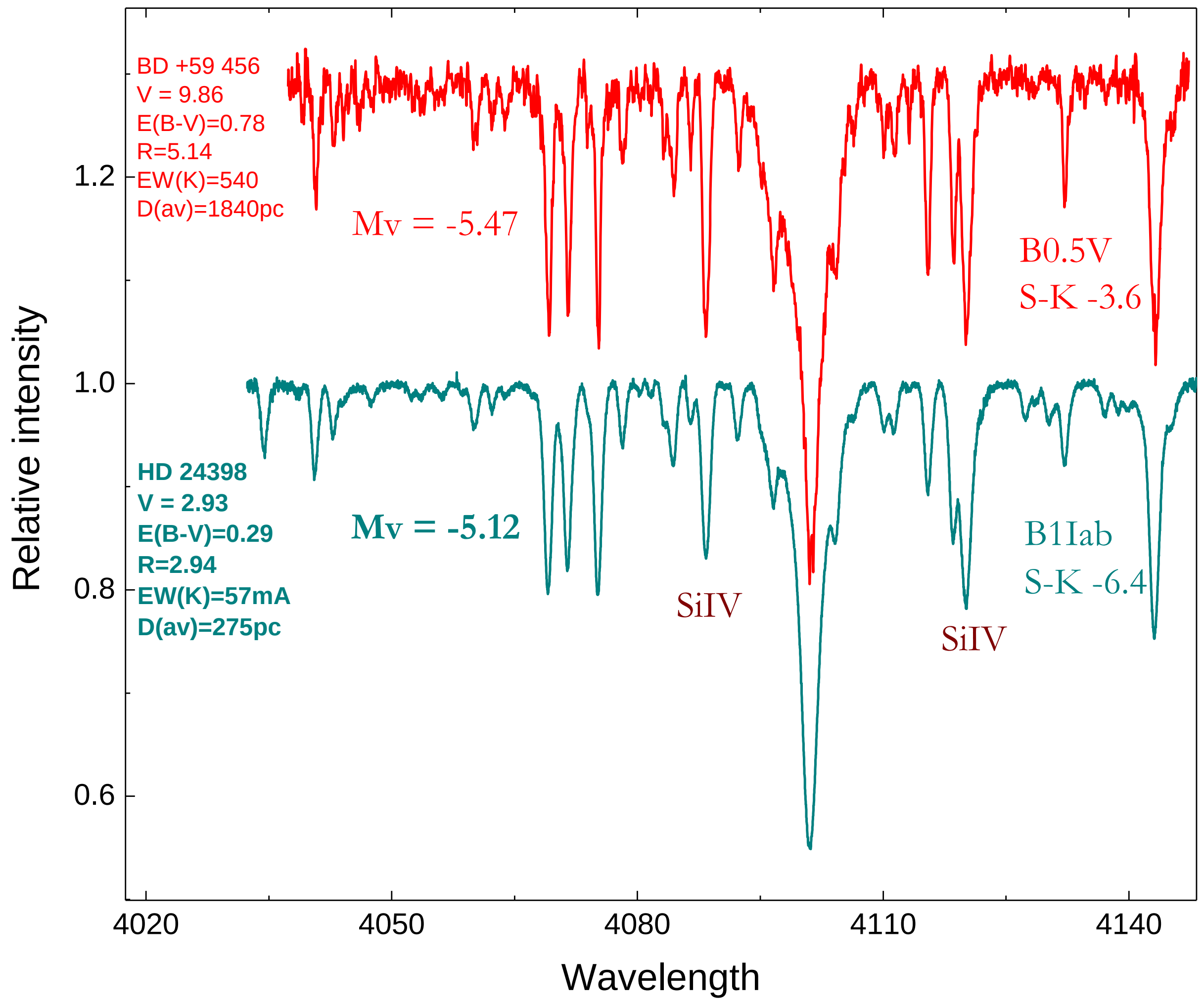
$$D = 77 + (2.78 + 2.6/(K/H - 0.932)) * H$$



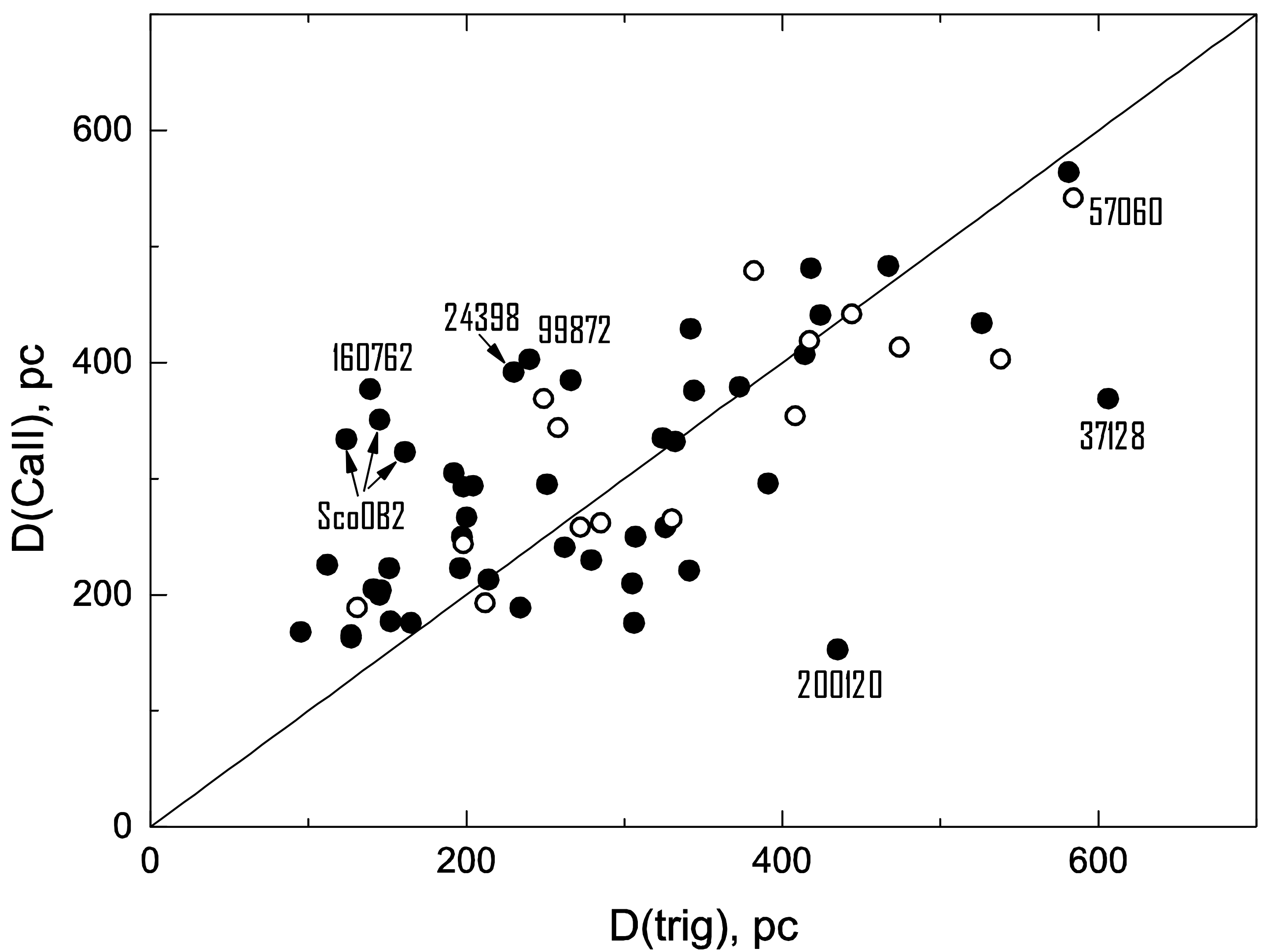
Does identical Sp/L leads to identical M?



Absolute magnitudes calculated using CaII method and the literaturę data (right)



CaII and trigonometric distances are accordant

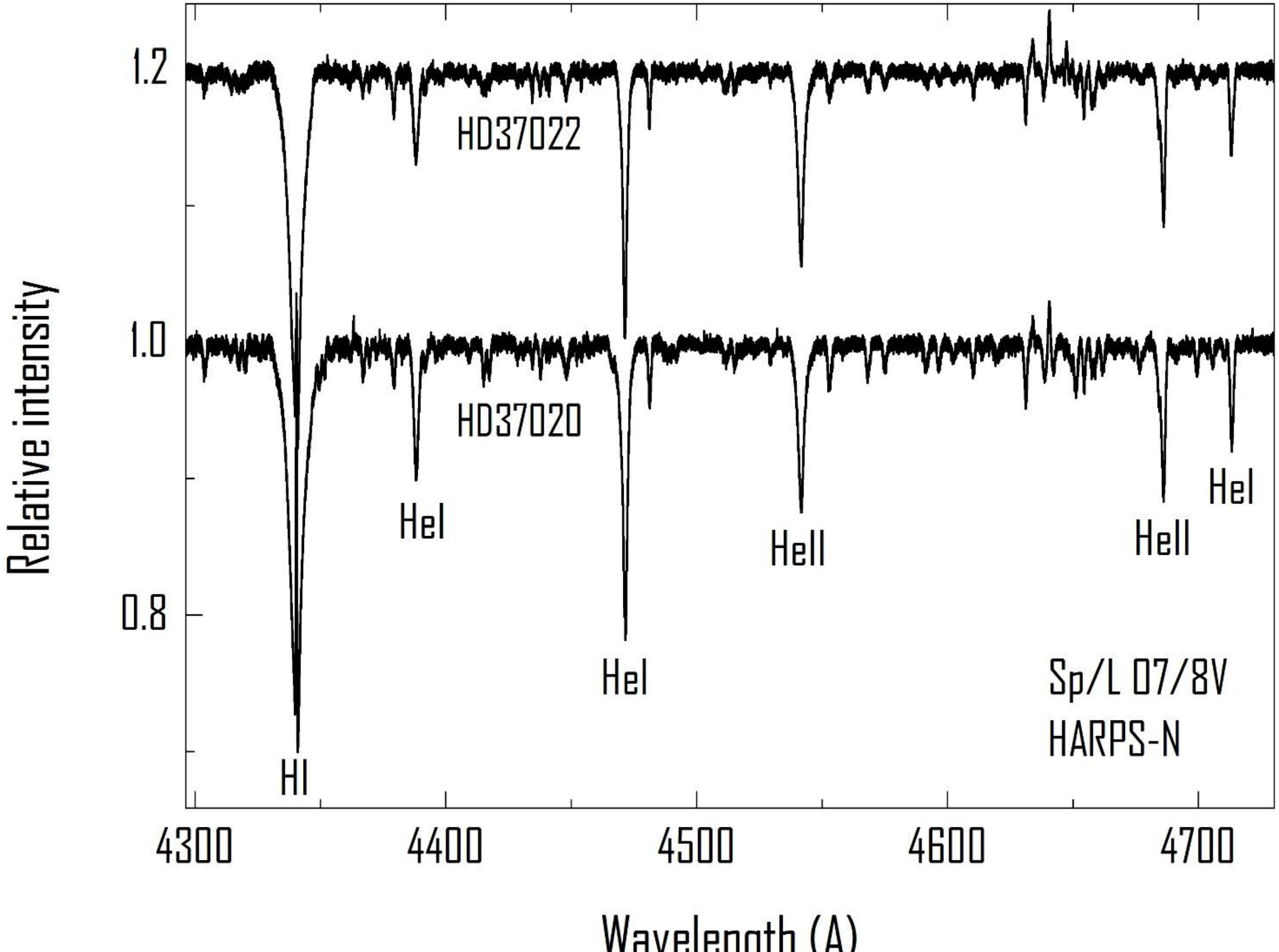


What the correlations do say us?

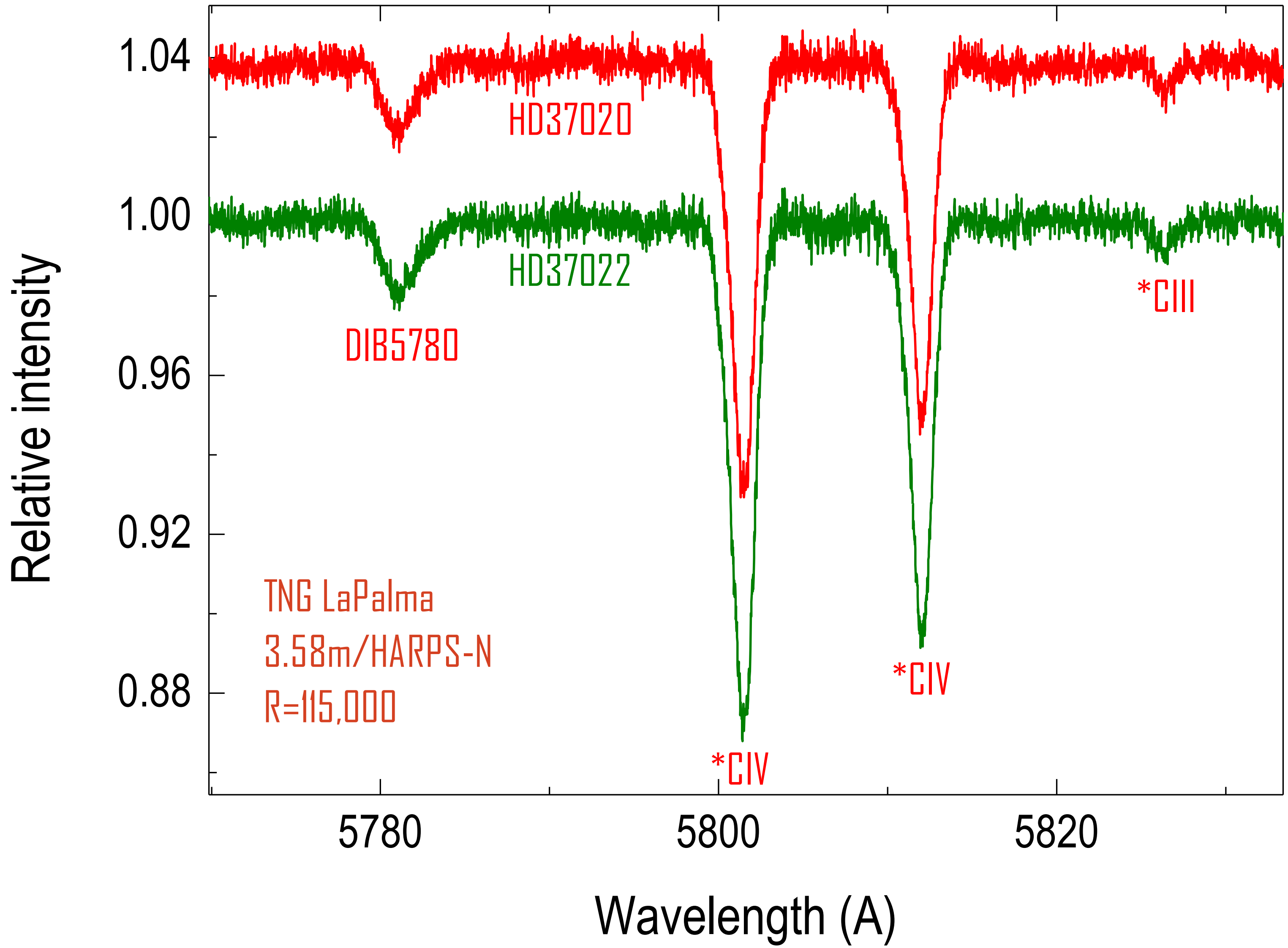
- MW disc is pretty evenly filled with reasonably tiny clouds revealed most evidently by the H and K interstellar lines
- Individual Hipparcos parallaxes may suffer pretty large errors
- Other interstellar features show the radial components either saturated (NaI) or very weak (CH, CH+).

Orion Trapezium

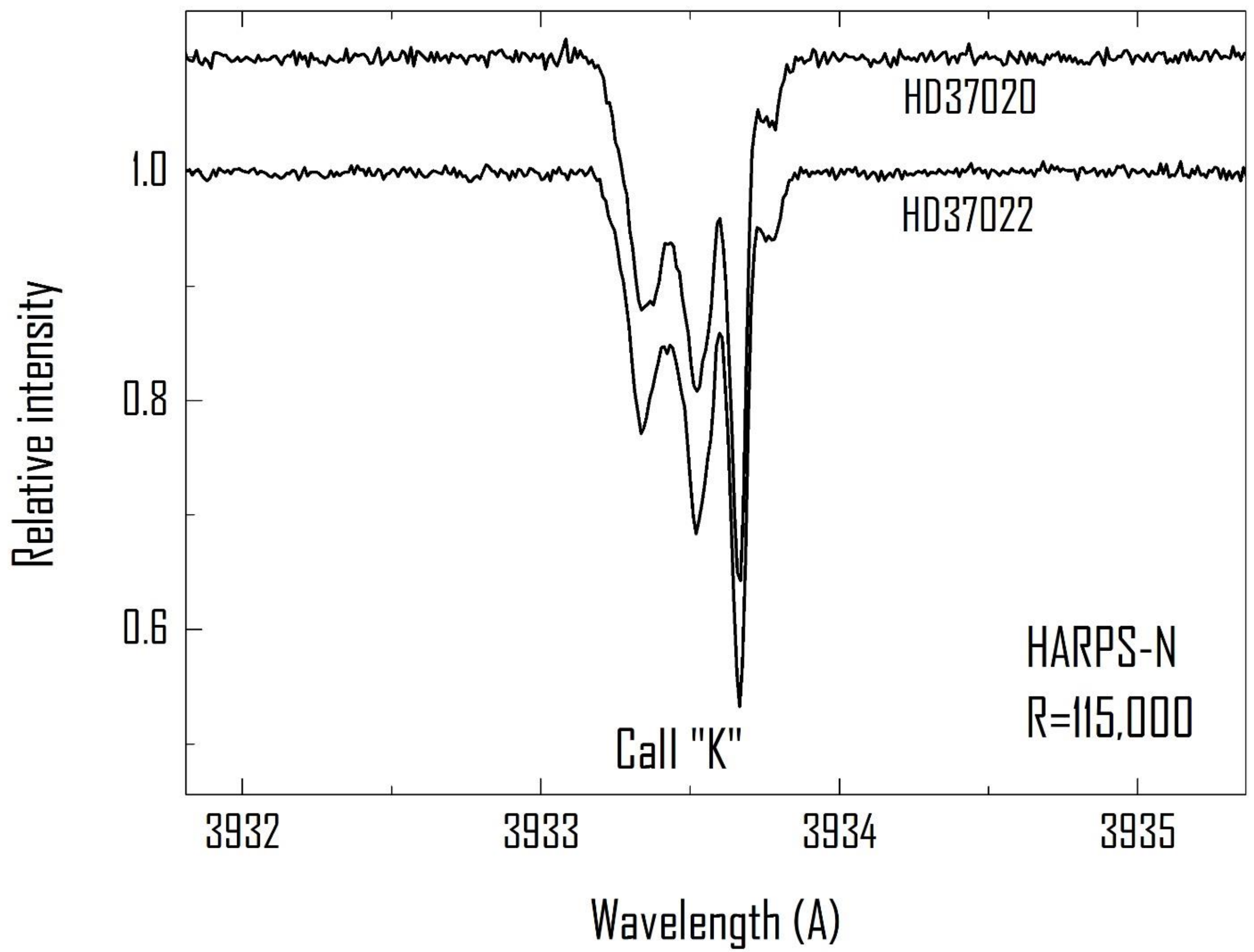
Spectra of two selected Trapezium stars are nearly identical



Stellar and interstellar features in the two Trapezium stars



Profiles of the „K” in bothTrapezium stars



Most reliable distance to the Trapezium

A&A 474, 515–520 (2007)
DOI: 10.1051/0004-6361:20078247

Astronomy & Astrophysics

The distance to the Orion Nebula

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ABSTRACT

We have used the Very Long Baseline Array to measure the trigonometric parallax of several member stars of the Orion Nebula Cluster showing non-thermal radio emission. We have determined the distance to the cluster to be 414 ± 7 pc. Our distance determination allows for an improved calibration of luminosities and ages of young stars. We have also measured the proper motions of four cluster stars which, when accurate radial velocities are measured, will put strong constraints on the origin of the cluster.

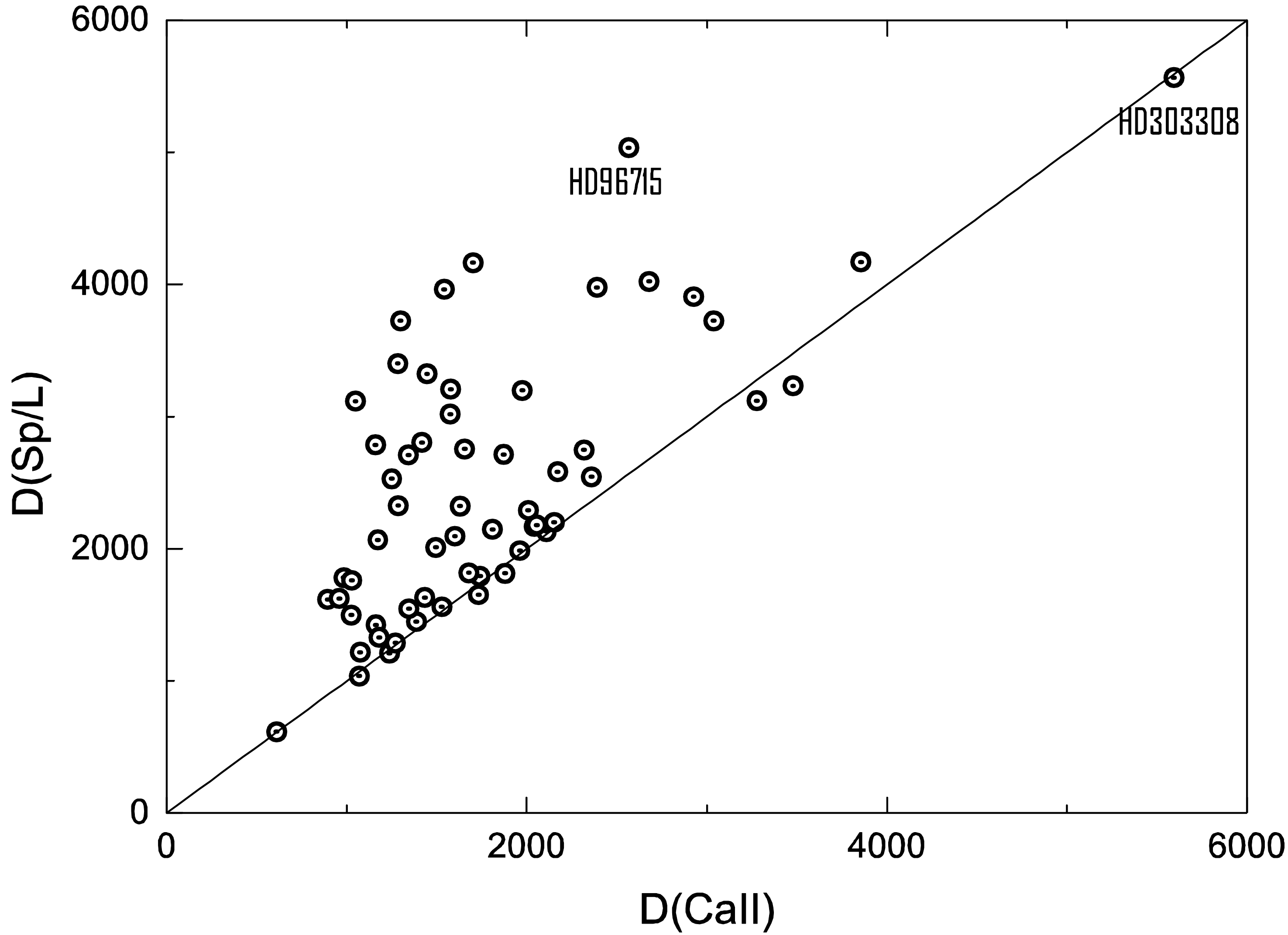
Key words. stars: pre-main sequence – radio continuum: stars – techniques: interferometic – astrometry

CaII and spectrophotometric distances to the Trapezium stars

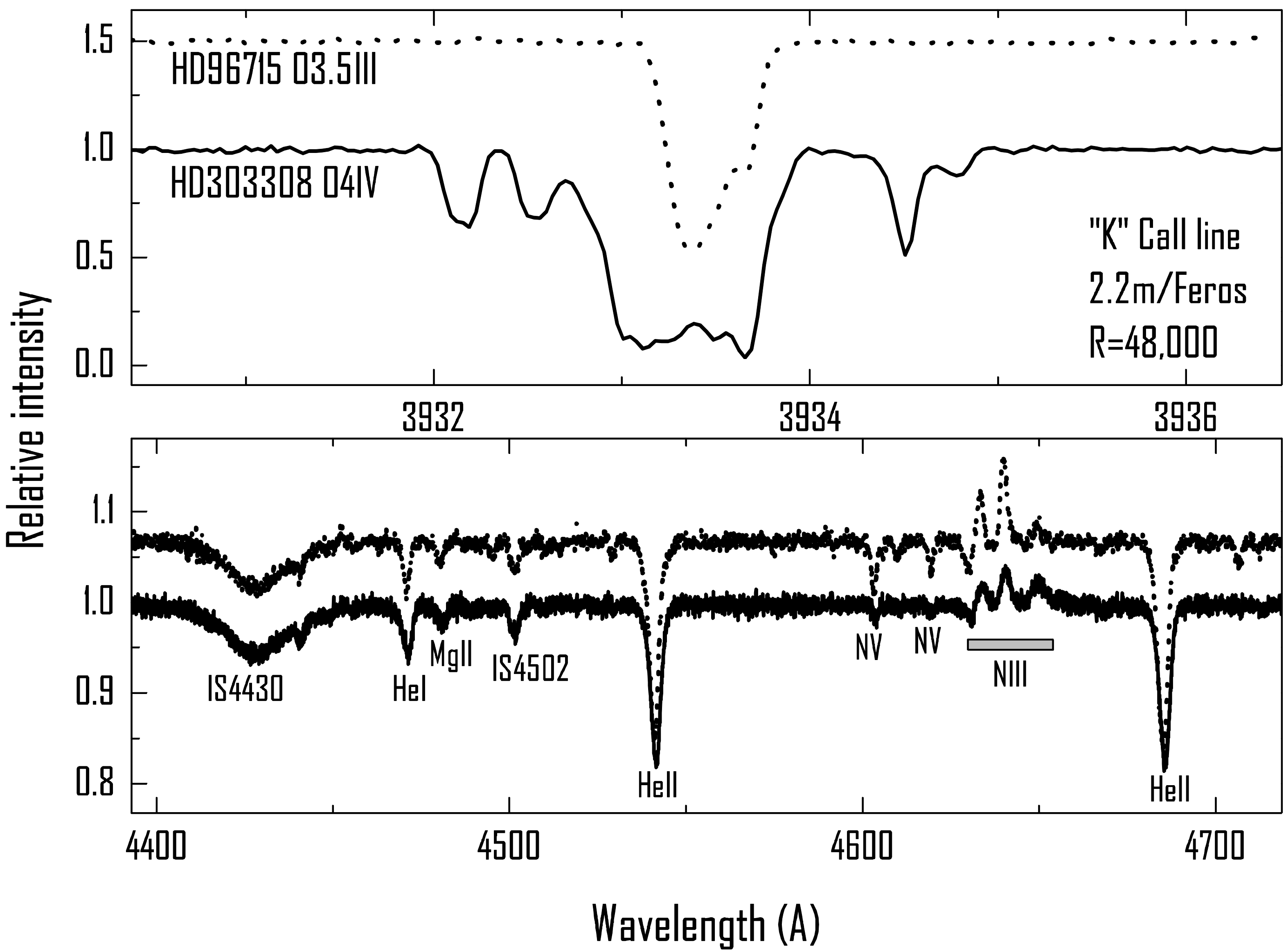
Table 2. Stellar and measurements data

star	Sp/L	V	B-V	M_V	EW(K) (mÅ)	EW(H) (mÅ)	D(CaII)	D(Sp)	R(FM)	E(B-V)	origin
37020	O8V	6.74	0.03	-4.9	108.7±1.4	60.1±1.3	422	905	5.8	0.32	HARPS-N
37022	O7.5V	5.14	0.03	-5.05	106.7±1.2	58.5±1.2	410	419	6.4	0.32	HARPS-N
					108.0±0.9	59.1±0.9	413	—	6.4		Feros
					106.0±4.7	58.4±4.4	411	—	6.4		Grams
					105.5±0.9	58.1±0.8	409	—	6.4		UVES
37023	B1V	6.70	0.08	-3.2	110.8±1.8	61.1±1.5	427	417	5.8	0.31	Feros
					115.8±4.1	60.0±4.5	400	417	5.8		Grams

Strongly asymmetric scatter around the 1-1 line



Similar Sp/L and IS4430 DIB but very different CaII



Three principles of distance measuring

Standard rod	Standard candle	Column density of the interstellar medium
$D = 1/\pi$	$m-M=5lgD-5+A_V$ $A_V = R*E_{B-V}+C$	D~N(X) N(X)~EW(X)
Small angles; many objects out of range	R € (2.5;5.5) M (+/- 1m.5) – statist. E_{B-V} ~OK. (+/-0.05) C ?	ISM is not continuous; Only one calibration

Conclusions

Every method of distance determination has some limitations:

Trigonometric parallax is limited to relatively nearby stars (expected extension by GAIA)

Spectroscopic parallax requires calibrations of M for Sp/L, simultaneous spectral and photometric observations and individual extinction law

CaII method works properly only in the Milky Way disc but is based on one calibration only